ENERGY AND ENVIRONMENTAL ANALYSIS, INC.

Final Report:

Distributed Generation Operational Reliability and Availability Database

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January 2004

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ES-1 Objectives

The increased deployment of Distributed Generation (DG)/Combined Heat and Power (CHP) has been identified as a means to enhance both individual customer reliability and electric transmission and distribution system reliability. DG/CHP reliability and availability performance relates to several significant issues affecting market development. The reliability/availability profiles for DG/CHP systems can affect electric standby charges and back-up rates, the value of ancillary services offered to Independent Transmission System Operators (ISO), local grid stability and reliability, customer power delivery system reliability, and customer economics. Interest in power reliability has heightened in recent years in light of high-profile system.

This project represents the first attempt to establish baseline operating and reliability data for DG/CHP systems in more than a decade. Specific objectives of this project were to:

- Establish baseline operating and reliability data for distributed generation systems
- Identify and classify DG/CHP system failures and outages
- Determine failure modes and causes of outages
- Quantify system downtime for planned and unplanned maintenance
- Identify follow-on research and/or activities that can improve the understanding of reliability of DG/CHP technologies.

The primary deliverable of the project is a database framework populated with 121 DG/CHP units which is used to estimate the operational reliability (OR) of various DG/CHP technologies. From the data, key operational reliability (OR) measures were calculated. These objectives were accomplished with the valued participation of actual DG/CHP users and access to their operations and maintenance data.

ES-2 Technical Approach

The methodology for assessing the operational reliability of DG systems was to establish baseline operating and reliability data for DG/CHP systems through an exhaustive collection of data from a representative sample of operating facilities. Data was collected from user maintenance logs, operation records, manufacturers' data, and other available sources. The project team calculated key operational reliability indices. We then identified and classified DG system failures and outages for various types of technologies and applications. Finally, the project team assessed forced outage causes and quantified system downtimes for planned and unplanned maintenance. The final work product was a database framework of operational reliability data for DG/CHP systems that characterizes unit reliability over a two year period.

The technical approach used was based on the following guidelines:

- Operational reliability data should address a diverse set of prime mover technologies and applications
- Data collection process will have to rely heavily on user participation and their records
- Procedures for collecting, processing, and analyzing data must be tightly controlled.

The scope of work consisted of the following tasks:

- Review of Prior Work
- Identify and Select Candidate Sites
- Collect Operating Data
- Reduce and Analyze Data
- Assess Reliability
- Perform Outage Cause Assessment

The project team conducted an exhaustive review of public and private databases to screen potential sites to populate the database. Two databases in particular that were used extensively are the PA Consulting/Hagler-Bailly and Energy Information Administration databases of non-utility power plants. In a parallel effort to screen sites, the project team utilized its network of contacts at manufacturers, developers, gas utilities, associations, and packaged cogeneration players. As the databases of existing facilities become less accurate for sites less than 1 MW in size, these personal contacts were important in identifying the smaller sized sites. In addition, we mailed letters to various stakeholders.

The project team collected raw data for 121 DG/CHP units. These 121 units represented 731.33 MW of installed capacity and operated for 1,669,411 service hours. Data concerning 2,991 outage events were collected. Each event was described using a consistent equipment taxonomy (refer to Appendix B) and outage codes consistent with IEEE Standard 762. The primary sources of data included O&M log books, outage summary reports, and contractor service reports.

The project team developed a data collection plan that addressed the framework and procedures used to screen potential participants, enter data and analyze OR performance. To analyze data we developed a database framework upon which additional sites and data can be added.

The project team calculated OR measures consistent with industry practices. Measures include availability factor, forced outage rate, scheduled outage factor, service factor, mean time between forced outage, and mean down time.

ES-3 Results

The OR performance of a unit is affected by many factors including technology and operations and maintenance practices. The units in the sample were distributed into nine technology groups as follows:

Reciprocating Engines
Group 1: <100 kW
Group 2: 100 - 800 kW
Group 3: 800 kW – 3 MW

Fuel Cells
Group 4: <200 kW

Gas Turbines
Group 5: 500 kW – 5 MW
Group 6: 5 MW – 20 MW
Group 7: 20 – 100 MW

Microturbines
Group 8: <100 kW

Steam Turbines
Group 9: <25 MW

When compared to electric utility units reported by the North American Electric Reliability Council Generating Availability Data System (NERC GADS), the DG/CHP units reviewed in this project demonstrated comparable to superior OR performance. OR statistics for units are shown tables ES.1 through ES.3.

Table ES.1 – Summary Statistics for Reciprocating Engine Systems

Reciprocating Engines	<100kW			100-800 kW			800-3000 kW		
Number Sampled	14			8			18		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	96.27	97.93	99.00	84.55	95.99	99.93	91.14	98.22	100.00
Forced Outage Rate (%)	0.86	1.76	3.07	0.00	1.98	5.05	0.00	0.85	6.63
Scheduled Outage Factor (%)	0.26	0.73	1.33	0.07	2.47	14.22	0.00	1.12	3.42
Service Factor (%)	68.20	75.11	79.60	2.06	51.76	95.43	1.50	40.59	91.39
Mean Time Between Forced Outages (hrs)	505.96	784.75	1376.60	361.18	1352.26	4058.71	263.00	3582.77	14755.30
Mean Down Time (hrs)	7.29	13.71	24.21	12.50	50.66	173.05	0.00	27.06	91.91

Table ES.2 – Summary Statistics for Gas Turbine Systems

Gas Turbines	0.5-3 MW			3-20 MW			20-100 MW		
Number Sampled		11			21			9	
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	88.88	97.13	100.00	88.56	94.97	99.60	86.33	93.53	99.45
Forced Outage Rate (%)	0.00	2.89	18.84	0.00	2.88	9.07	0.00	1.37	6.63
Scheduled Outage Factor (%)	0.00	0.99	4.57	0.00	2.39	11.44	0.00	5.14	13.50
Service Factor (%)	5.33	57.93	97.27	6.26	82.24	99.01	70.27	88.74	99.45
Mean Time Between Forced Outages (hrs)	765.62	2219.72	4318.00	216.77	1956.46	15298.00	536.00	3604.62	17424.00
Mean Down Time (hrs)	0.17	65.38	325.09	2.77	68.63	501.75	21.29	75.30	288.50

Table ES.3 – Summary Statistics: Fuel Cells and Steam Turbines

Other Technologies	Fuel Cells <200kW			Steam Turbines <25MW		
Number Sampled		15			25	
	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	42.31	76.84	95.04	72.37	92.02	99.82
Forced Outage Rate (%)	4.31	22.94	57.51	0.00	2.34	16.41
Scheduled Outage Factor (%)	0.48	0.92	1.23	0.00	6.01	27.63
Service Factor (%)	42.27	74.01	92.21	3.37	81.12	99.65
Mean Time Between Forced Outages (hrs)	1416.71	2004.47	2696.33	120.18	5317.73	29585.00
Mean Down Time (hrs)	66.92	369.24	1686.83	5.51	292.06	4848.00

During the course of the project, specific units were observed to exhibit both very good to poor OR performance. In almost all technology groups, subsystems other than the prime movers themselves contributed significantly to occurrence of forced outage events. Many events that occur are the result of random equipment failures expected of any complex power system. Other events may be nonrandom in nature, indicating problems that may relate to issues pertaining to the unit design or installation. This project did not result in the identification of any such systemic problems. Most failures within technology groups appear to be random occurrences of short duration.

ES-4 Conclusions and Recommendations

The database is intended to establish a baseline of OR data on DG/CHP and allow current and potential users to benchmark reliability. The methodology and framework for recording and analyzing data is straight forward, repeatable and consistent with industry standards. It should be noted that the data reviewed for this project is only for 2000-2002 time period. The database does not include large samples in all technology groups. It is structured to accommodate more units and technology groups in a follow-on effort. Future periodic updating and maintenance on a regular basis will ensure continued usefulness and increase the confidence in the measures calculated.

The DG/CHP Reliability and Availability Database provides a general framework for recording operating data and analyzing OR performance. It provides a solid foundation for future improvements and enhancements. Recommended improvements to the database framework include:

- Add additional units in under-represented technology groups to improve the robustness of the data
- Update data on an annual basis to include years of operation beyond the original 2000-2002 period
- Include microturbines with at least two years of operations (not including R&D demonstration) along with fuel cells with similar operating history in a separate database pertaining to emerging DG/CHP technologies

Any follow-up effort needs an efficient site identification and data collection process. For example, monthly data submission by site operators with secure web-based data entry system would reduce the labor costs associated with data collection substantially.

1 INTRODUCTION

This report documents the results of an 18 month project entitled, "Distributed Generation Market Transformation Tools: Distributed Generation Reliability and Availability Database," sponsored by Oak Ridge National Laboratory (ORNL), Energy Solutions Center (ESC), New York State Energy Research and Development Authority (NYSERDA), and Gas Technology Institute (GTI).

Using operations and maintenance field data provided by distributed generation (DG)/combined heat and power (CHP) project operators, owners, and developers, the project team analyzed the operational reliability (OR) performance of various onsite generation technologies. OR generally refers to the reliability, availability, and maintainability attributes of a process system and its components. Specifically, the project team analyzed event histories for 121 DG/CHP units over a two-year time period between 2000 and 2002. A data collection and management software tool was developed as well as a database. This project represented the first attempt to establish baseline operating and reliability data for DG/CHP systems in more than a decade.

Using the raw data collected, the project team calculates summary level OR statistics for 121 units within specific technology groups. Technologies assessed included reciprocating engines, gas turbines, fuel cells, and steam turbines. The methodology and OR measures used in this project are consistent with established industry standards. The results of this project provide various stakeholders with insights to the actual OR performance of onsite power generation systems. The first version of this database provides a solid foundation upon which additional units can be added or periodic annual updating of data can be performed in the future.

The following chapters of this report explore and characterize, in turn:

- DG/CHP reliability background;
- technical approach used in the development of the reliability and availability database;
- summary operational and reliability data collected in this project;
- breakdown and analysis of event causes, and;
- Conclusions and recommendations.

2 BACKGROUND

2.1 Reliability and DG/CHP

Distributed Generation (DG) is projected to grow in importance in industrial markets. Distributed Generation represents significant opportunities for industrial customers to reduce their energy costs, improve reliability of electric service, improve their productivity by reducing costly power outages, and increase energy efficiency and reduce emissions through recovering waste heat in combined heat and power (CHP) applications.

The U.S. Department of Energy (DOE) and Oak Ridge National Laboratory (ORNL) are leaders in the development of efficient, clean DG technologies for industrial customers through partnerships with industry. As part of these efforts, DOE developed a strategy to address key barriers that must be overcome in order to accelerate the deployment of DG technologies into the industrial sector. DOE and ORNL identified the need for improved information on DG/CHP system reliability and availability. This information would allow end-users, developers and DOE to better identify and evaluate DG opportunities that provide the greatest benefit to all stakeholders. Consistent with their respective plans to accelerate the development of the CHP market, New York State Energy Research and Development Authority, Energy Solutions Center, and Gas Technology Institute cofunded the project.

2.1.1 Existing CHP Market

There are approximately 77,000 MW of CHP capacity in the United States today. This is shown in Table 2.1. The U.S. Department of Energy and others project significant growth in onsite power generation over the next decade. A key to sustaining this growth and accelerating general acceptance of onsite power generation is the achievement of high levels of reliability across all major DG/CHP technology markets.

Table 2.1 - Installed CHP by Sector

	Installed CHP Capacity by Sector (MW)			
Prime Mover	Industrial	Commercial	Other	Total
Boiler/Steam Turbine	2,336	20,080	1,595	24,011
Combined Cycle	2,589	33,939	736	37,264
Combustion Turbine	2,782	8,812	2,843	14,438
Recip Engine	818	330	37	1,184
Other	35	170	1	206
Total	8,560	63,330	5,212	77,102

Source: Energy and Environmental Analysis/Energy Nexus Group, Hagler Bailly Independent Power Database

2.1.2 Value of Operational Reliability

Distributed generation/combined heat and power (DG/CHP) are expected to play a significant role in the energy industry for the next decade. Factors affecting growth include fuel price stability, installed capital costs, and the ability of the user to generate energy when needed, i.e., operational reliability. Stakeholders in the developing DG/CHP market need assurance that power can be delivered reliably and at acceptable costs. Interruptions in service have a considerable affect on the revenue cash flow and/or cost savings from an onsite power project.

2.2 Project Objectives

The increased deployment of Distributed Generation (DG)/Combined Heat and Power (CHP) has been identified as a means to enhance both individual customer reliability and electric transmission and distribution system reliability. DG/CHP reliability and availability performance relates to several significant issues affecting market development. The reliability/availability profiles for DG/CHP systems can affect electric standby charges and back-up rates, the value of ancillary services offered to Independent Transmission System Operators (ISO), local grid stability and reliability, customer power delivery system reliability, and customer economics. Interest in power reliability has heightened in recent years in light of high-profile system.

Specific objectives of this project were to:

- Establish baseline operating and reliability data for distributed generation systems
- Identify and classify DG/CHP system failures and outages
- Determine failure modes and causes of outages
- Quantify system downtime for planned and unplanned maintenance
- Identify follow-on research and/or activities that can improve the understanding of reliability of DG/CHP technologies.

The primary deliverablse of the project is a database framework populated with 121 DG/CHP units which is used to estimate the operational reliability (OR) of various DG/CHP technologies. From the data, key operational reliability (OR) measures were calculated. These objectives were accomplished with the valued participation of actual DG/CHP users and access to their operations and maintenance data.

2.3 Project Workscope

The methodology for assessing the operational reliability of DG systems was to establish baseline operating and reliability data for DG/CHP systems through an exhaustive collection of data from a representative sample of operating facilities. Data was collected from user maintenance logs, operation records, manufacturers' data, and other available sources. The project team calculated key operational reliability indices. We then identified and classified DG system failures and outages for various types of technologies and applications. Finally, the project team assessed forced outage causes and quantified system downtimes for planned and unplanned maintenance. The final work product was a database framework of operational reliability data for DG/CHP systems that characterizes unit reliability over a minimum two-year period. This database can be augmented with additional sites in the future or be improved to allow for additional operating data to be added on a regular basis, e.g., monthly.

The database will allow individual DG facility managers to better understand reliability and availability performance of their particular units and also determine how their facilities compare with other DG resources. Detailed information on DG reliability and availability performance will enable potential DG users to make a more informed purchase decision, and will help policy makers quantify potential grid system benefits of customer-sited DG.

The workscope consisted of the following tasks:

- Review of Prior Work
- Identify and Select Candidate Sites
- Collect Operating Data
- Reduce and Analyze Data
- Assess Reliability
- Perform Forced Outage Cause Assessment

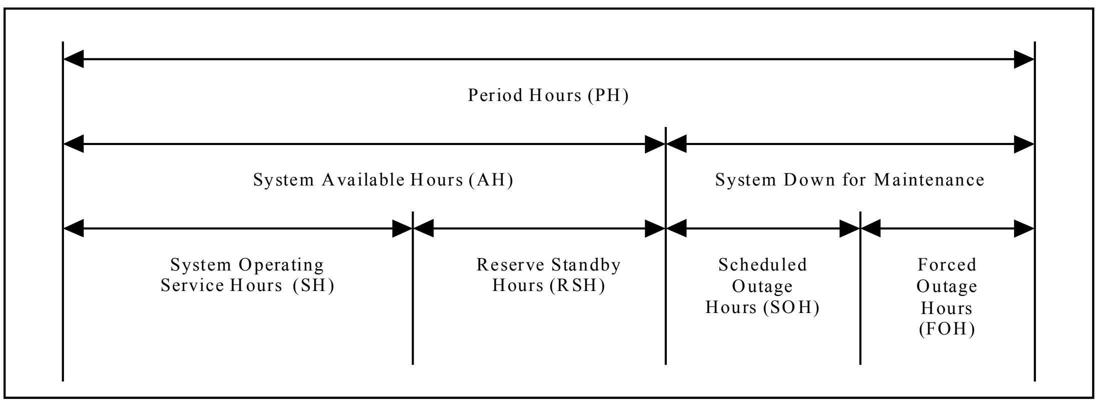
2.4 Operational Reliability Terms and Definitions

A generation unit can reside in one of three independent states. Those states are:

- Operating and producing electrical or thermal energy
- Not operating due to planned or unplanned maintenance
- Not operating, but capable of energy production (reserve standby)

These states are shown in Figure 2.1 together with the calculations used to determine OR performance. The operational reliability measures shown in Figure 2.1 are consistent with ANSI/IEEE Standard 762 *Standard Definitions for Use in Reporting Electrical Generating Unit Reliability, Availability, and Productivity*. IEEE Standard 762 contains 66 reliability related terms and 25 OR performance indices (none of which is explicitly named "reliability").

Figure 2.1 – Operational Reliability Terms and Definitions



Reliability Performance Indices	Formula
Period of Demand (POD): Measures the time the unit was planned to operate.	POD = PH - RSH- SOH
Availability Factor (AF, %): Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance.	$AF = \frac{(PH - SOH - FOH) * 100}{PH}$
Forced Outage Rate (FOR, %): Measures portion of downtime due to unplanned factors.	$FOR = \frac{FOH * 100}{(SH + FOH)}$
Scheduled Outage Factor (SOF, %): Measures percent of time set aside for planned maintenance.	$SOF = \frac{SOH * 100}{PH}$
Service Factor (SF, %): Percent of total period hours the unit is on-line – varies due to site-related or economic factors.	$SF = \frac{SH * 100}{PH}$
Mean Time Between Forced Outages (MTBFO): Measures the nominal time between unscheduled forced outages.	$MTBFO = \frac{SH}{\# \text{ Forced Outages}}$
Mean Down Time (MDT): Measures the nominal duration the unit is down during maintenance events.	$MDT = \frac{SOH + FOH}{\# \text{ Forced Outages} + \# \text{ Plant Outages}}$

3 TECHNICAL APPROACH

3.1 Introduction

The methodology for assessing the operational reliability of DG systems was to establish baseline operating and reliability data for DG/CHP systems through an exhaustive collection of data from a representative sample of operating facilities. Data was collected from user maintenance logs, operation records, manufacturers' data, and other available sources. The project team calculated key operational reliability indices. We then identified and classified DG system failures and outages for various types of technologies and applications. Finally, the project team assessed forced outage causes and quantified system downtimes for planned and unplanned maintenance. The final work product was a database framework of operational reliability data for DG/CHP systems that characterizes unit reliability over a two year period.

The technical approach used was based on the following guidelines:

- Operational reliability data should address a diverse set of prime mover technologies and applications
- Data collection process will have to rely heavily on user participation and their records
- Procedures for collecting, processing, and analyzing data must be tightly controlled.

3.2 Review Prior Work

The project team conducted a review of the methodologies of data collection and reliability assessment used in several previous studies. In addition, GTI was able to provide programming support for a consistent and uniform approach to the collection of data and its management based on its prior work in cogeneration system reliability.

3.2.1 Key References

While many sources were identified in the existing body of work on power plant reliability, including those by the Electric Power Research Institute, North American Reliability Council/Generating Availability Data System, and the US Army, several key references represent the prior work most directly applicable to the objectives and methodology of this project. They include the following:

- GRI/ARINC Cogeneration Operational Reliability Database
- FOREMAN Software User Guide – An Operations and Maintenance Data Manager and Reliability Reporting System
- IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems

- ANSI/IEEE 762 Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity
- Reliability Survey of 600-1800 kW Diesel and Gas-Turbine Generating Units, ARINC, IEEE ICPSD 89-02

As a result of the review of prior work, a preliminary database structure was developed. The structure will consist of three primary components. The three components are based on Facility Information, Unit/Subsystem/Component Information, and Event Descriptions. The review of prior work also helped in developing the unit selection criteria and the determination of desireable hours of operation in order to ensure confidence in the validity of the operational reliability indices calculated. This is described in the unit selection section below.

3.3 Candidate Screening and Selection

The objective of the screening process was to identify candidate units that will be considered for inclusion in the project. The project team conducted an exhaustive review of public and private databases to screen potential sites to populate the database. Two databases in particular that were used extensively are the PA Consulting/Hagler-Bailly and Energy Information Administration databases of non-utility power plants. In a parallel effort to screen sites, the project team utilized its network of contacts at manufacturers, developers, gas utilities, associations, and packaged cogeneration players. As the databases of existing facilities become less accurate for sites less than 1 MW in size, these personal contacts were important in identifying the smaller sized sites. In addition, we mailed letters to various stakeholders. The text of a targeted letter to contacts at manufacturers, developers, gas utilities, associations, and packaged cogeneration players is shown in Appendix A.

Sites from the databases as well as those identified by contacts were contacted via telephone to screen the possibility of inclusion in the final database.

3.3.1 Screening Process

The development of a final screening questionnaire for potential sites was a two step process. Initially the following set of questions was used to determine the suitability of the candidate units.

Basic Questions for screening

General

1. Facility Name
2. Contact/phone/fax/email
3. Prime mover models/# of units
4. Fuel
5. Thermal application
6. Utility connected or isolated
7. Facility or contractor maintained

8. Operation baseload/cycling/peak/standby

Questions on Data Availability – Are these tracked and documented?

1. Maintenance logs
2. Monthly operating hours data
3. Number of unit starts
4. Records of scheduled maintenance
5. Records of corrective maintenance

Operations and Maintenance Questions – Is there an approximate understanding of these measurements

1. What are the approximate service factors for plant units?
2. What percentage of the time does each unit run?
3. How many times per month does each unit shut down for corrective maintenance?
4. How many times are the units started per month?
5. What are the approximate annual scheduled outage hours?
6. Who performs the scheduled maintenance?

Design Questions

1. Have equipment modifications been made? Describe.
2. Are emission control devices used? Describe.
3. What is nameplate electrical output rating?
4. What is thermal output? If applicable

Questions about administration

1. Can ONSITE Energy obtain permission to review maintenance and operating records?
2. Will plant transmit (mail or electronic) copies of records to ONSITE?
3. Will a site visit be required to review records?

Follow-up Actions and recommendation to include in DB

This approach resulted in being too time intensive in a trial, especially considering that thousands of potential sites exist in the databases being used.

A revised screening that was effectively reduced to validating the plant information the project team has and a series of yes and no questions was developed. Those questions as well as a project background “preamble” follow.

Introduction

On behalf of the U.S. Depart of Energy and Oak Ridge National Laboratory, Energy Nexus Group, a subsidiary of ONSITE Energy, is developing an operational reliability and availability database for on-site generation technologies.

The final work product will be a database of operational reliability data for DG/CHP systems. The database will allow individual DG/CHP facility managers to better understand reliability and availability performance of their particular units and also determine how their facilities compare with other resources. Detailed information on DG/CHP reliability and availability performance will enable potential users to make a more informed purchase decision, and will help policy makers quantify potential grid system benefits of customer-sited generation.

We are seeking your assistance in identifying onsite generation sites with at least two years of operating experience to populate the database. We are currently in the process of identifying and screening potential sites to populate the database and could use your assistance.

Your facility was identified as a potential site (at the recommendation of a manufacturer of your equipment, packager/distributor/project developer, or through a review of databases of existing DG or CHP facilities).

To be in the final database population we will ultimately need the following essential data:

- monthly operations reports that describe unit electric generation and engine service hours
- maintenance log books and service reports that describe planned and unplanned outage maintenance and outage durations

At this point in time we are screening candidate sites and have just a basic set of questions.

Do you have some time to answer some questions?

General (in some cases validate the information from our databases)

1. Facility Name
2. Contact/phone/fax/email
3. Prime movers/# of units
4. Fuel
5. Thermal application (CHP)/power only
6. Years of operation

Yes/No Questions on Data Availability – Are they tracked and documented?

1. Is there a central data source for maintenance information such as maintenance logs?
2. Do you collect maintenance data?
3. Do you collect operating data?
4. Do you record all outages planned and unplanned?
5. Do you keep logs for scheduled maintenance?
6. Do you track maintenance time and corrective maintenance actions in the case of forced outages?
7. Is there a maintenance program currently in place?
8. Can ONSITE Energy obtain permission to review maintenance and operating records?
9. Will plant transmit (mail or electronic) copies of records to ONSITE?
10. Will a site visit be required to review records?

Follow-up Actions and recommendation to include in DB

More than 2000 potential candidate sites were screened and reduced to 179 sites representing 377 DG/CHP units.

3.3.2 Unit Selection Criteria

Of the nearly 400 DG/CHP units that passed our screening process, 121 units were ultimately included in the first version of the database. Units were eliminated due to lack of data, excessive time required of plant staff to assemble data, and budget constratints of the project. Additonal units can be added to the database framework in the future. The breakdown of the 121 units is shown Figure 3.1 and 3.2.

Figure 3.1 - Distribution of Sample by Technology by Units (n=121)

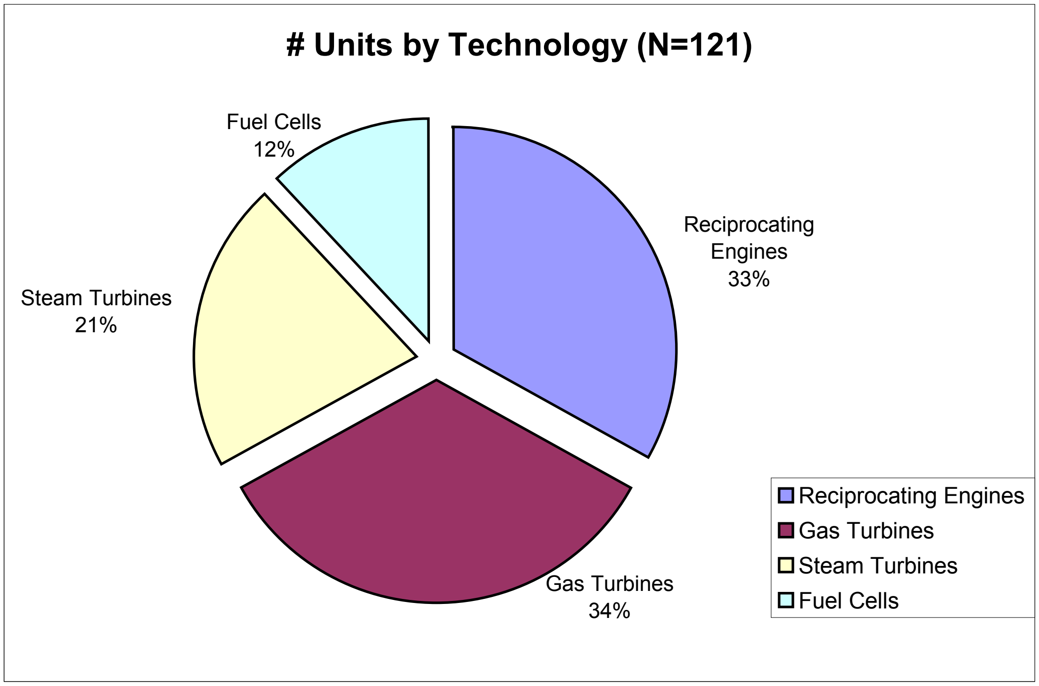
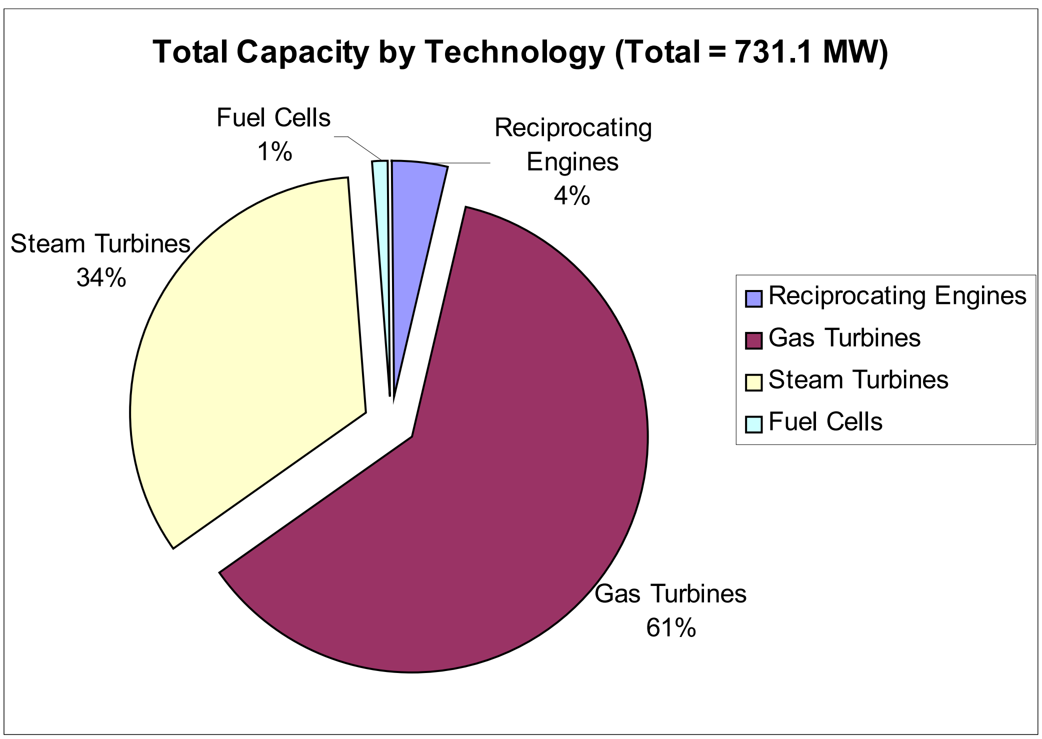


Figure 3.2 - Distribution of Sample by Technology by Capacity



Originally, units were intended to be selected based on the following criteria:

- Technology group
- Two full years of planned operation from 2000-2002
- Number of units at each site
- Completeness of O&M data
- Geography
- Customer sector (Industrial, Commercial, or Institutional)
- Willingness to cooperate and provide data

Nine Technology Groups were identified. They are listed below.

Reciprocating Engines
Group 1: <100 kW
Group 2: 100 - 800 kW
Group 3: 800 kW – 3 MW

Fuel Cells
Group 4: <200 kW

Gas Turbines
Group 5: 500 kW – 5 MW
Group 6: 5 MW – 20 MW
Group 7: 20 – 100 MW

Microturbines
Group 8: <100 kW

Steam Turbines
Group 9: <25 MW

The project team identified units in all technology groups that met the selection criteria with the exception of Group 8, microturbines. We believe this is due to the fact that units installed and operating by January 2000, the cut-off date for the required two years of operation to be included in this project were either pre-commercial or first generation microturbines. Developers and users would have had to provide data and characterize operational reliability of this class of technology based on units that would not be representative of the products that would ultimately be used in the market. They were justifiably reluctant to participate on this basis. In fact this was seen in the fuel cell data collected and analyzed for this project. Fuel cell operational reliability indices calculated were significantly lower than all other technology groups and what fuel cell manufacturers typically quote. Availability was greatly affected by downtime associated with unusually long delays (e.g., maintenance personnel response, availability of replacement parts, site operations) and not related to typical operation. For that reason, the project team elected not to collect data on microturbines at this time, but to structure the data collection software and database to easily accommodate microturbine data in the future.

Based on *IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems* and *GRI Report 93/0020 Reliability of Natural Gas Cogeneration Systems* two years of operating service per unit were desired in order to be considered for the database and calculate representative operational reliability indices. Two years of service corresponds to a 90% confidence that calculated indices are within 30% of the true unknown values.

The project team attempted to collect data on at least ten units in each technology group. We failed to do so for Technology Groups 2 and 7. The database was structured so that additional units can be added at some future date if follow-up activities are pursued.

3.4 Data Collection and Management Plan

The project team developed a data collection and management plan that addressed field data collection procedures, data sources, and analysis methods. Procedures for collecting, processing, and analyzing data had to be tightly controlled. GTI developed a Microsoft Access® based data collection and management software tool. The structure and description of the data collection software is in Appendix B. In addition to meeting the needs of the project team, the data input format had to be simple and consistent with user records and maintenance logs. Required operating data included:

- Monthly operation reports that describe unit service hours
- Maintenance log books
- Service reports that describe planned and unplanned outage maintenance
- Outage summary reports
- Contractor service reports

The data collection software was comprised of three primary components along with reporting and exporting features that allowed for post processing and analysis. The components consisted of the following:

- Plant Configuration – Characterize design and equipment features of each plant
- Subsystem Operations – Prime mover subsystem operations data for each plant
- Event Description – History of planned and unplanned maintenance, downtime duration, downtime cause, failure modes
- Reports – Summary reports for data contained in Plant Configuration, Subsystem Operations, and Event Description.

3.5 Collection of Raw Data

Based on the review of prior work and an initial round of feedback from potential candidate facilities, a set of desirable data collection parameters was identified. They are presented in Tables 3.1-3.4. The project team collected the described data while providing assurance to the participating facilities that they would not be mentioned by name in the project final report or database. Manufacturers and model numbers of units are also anonymous. This was required to ensure cooperation of manufacturers.

Each event relates to specific operating unit and is described by the type of outage, date of occurrence, outage duration, system/component cause, and the maintenance performed. From this detailed data, the project team is able to accurately derive operational reliability statistics.

Table 3.1 - Facility/Plant Information

Field Name	Field Description
Facility Name	Customer Site Name
Facility Code	Unique Facility Code Number Assigned
Facility Location	City/State
Contact	Name and Contact Information
Plant Type	Based on Primary Prime Mover Technology
Primary Fuel Type	Primary Fuel Type
Net Maximum Facility Capacity	Net Maximum Capacity for Plant in kW
Thermal Recovery Unit	Type of Heat Recovery

Table 3.2 - Unit Information

Field Name	Field Description
Code or Abbreviation	Technology Group and Subcategory
Unit Code	Unique Unit Code Number Assigned
Gross Output (kW)	Unit Gross Maximum Capacity in kilowatts
Thermal Rating (MMBtu/h)	Thermal Rating of Unit in MMBtu per Hour
Emissions Control	Emissions Control System Code
Modifications/Comments	Comment Field for Modifications to Engine Generator Unit

Table 3.3 - Unit Monthly Generation History Data

Field Name	Field Definition
Unit Code	Unique Unit Code
Date (MM/YY)	Date
Total Service Hours	Total run hours at any electrical output
Number of Attempted Starts	Number of starts attempted to bring the unit form shutdown to synchronism (repeated failures to start for the same cause without attempting corrective action are considered a single attempt)
Number of Successful Starts	Number of times the unit successfully started and synchronized

Table 3.4 - Event Log Data

Unit	Event Number Assigned	Start date/time	End date/time	Event Code	Derating (%)	Type of Maintenance	Event Maintenance is related	System Code	Component Code	Corrective Maintenance Taken (Y/N)	Corrective Action Code	Comments

There was a good deal of feedback from candidate sites regarding the event data being solicited. What the project team found was that it is difficult to document causes of outages. The host facilities in many cases do not document them well. In several instances, the detailed event history is just in the operator’s memory and not consistently documented (in some cases causes aren’t documented at all). Some manufacturers were reluctant to share the data. The information needed at a minimum to calculate the key statistics are when events (e.g., forced outages) actually occurred and their frequency relative to service hours. The project team had to compromise on the cause data available for event cause assessment. We were unable to obtain causal data for the entire set of events in our sample. A follow up effort may be asking the population to track and document better on a going forward basis.

Data was obtained through electronic mail, fax, standard mail, telephone interviews, and site visits. The problem most frequently encountered in obtaining data was the level of effort required by plant staff to assemble and reproduce the necessary records.

3.6 Post Processing of Operational Reliability Data

The project team calculated six operational reliability measures for each of the units in the sample from operating and event data collected for the project. These measures included availability factor (AF), forced outage rate (FOR), scheduled outage factor (SOF), service factor

(SF), mean time between forced outages (MTBFO), and mean down time (MDT). These indices were defined in the background section of this report.

The data on operations and outage events was arranged in a consistent record format. Data reduction was performed by examining operating data for each unit (e.g., period hours, operating hours, starts and start failures) and events in the operating and maintenance records to identify the timing, duration, and cause for each unit outage.

For each technology group, statistical tests of variance were conducted. There was wide variation in the calculated unit level measures within technology groups. Variations in calculated indices were generally attributed to the presence or absence of long downtime events (usually within the technology group) that were specific to the project site and characteristic of a design related factor.

Average OR indices for units of the same technology are calculated by first summing the data for each term in the equation for *n* units composing each technology group. For example, the average FOR is calculated as follows:

$$\mathrm{FOR} = \frac{\sum_{i=1}^{n} FOH}{\sum_{i=1}^{n} SH + \sum_{i=1}^{n} FOH} \quad \mathbf{x} \quad 100$$

3.7 Failure Cause Assessment

The project team characterized the frequency and duration of planned and forced events. Failure cause assessment was conducted for forced outage events. The frequency and duration of forced outage events caused by system/components was tabulated and assessed. This was done for all technology groups but Technology Group 4, fuel cells. Fuel cell operational reliability indices calculated were significantly lower than all other technology groups and what fuel cell manufacturers typically quote. Availability was greatly affected by downtime associated with unusually long delays (e.g., maintenance personnel response, availability of replacement parts, site operations) and not related to typical operation. These unusually long delays and the attribution of those long events to specific systems/components would have unfairly characterized the causes of those events and their typical duration.

As mentioned previously, the project team found it was difficult to document causes of outages. The host facilities in many cases do not document them well. In many cases, the detailed event history is just in the operator’s memory and not consistently documented (in some cases causes aren’t documented at all). There are outages in which causes are not documented. The failure cause analysis was conducted with noticeable events with not documented causal information.

4 SUMMARY OF DATABASE OPERATIONAL RELIABILITY

4.1 Introduction

This project represented the first attempt to establish baseline operating and reliability data for DG/CHP systems in more than a decade. The database developed includes 121 units representing 731.33 MW of installed capacity, operating for 1,669,411 service hours. The database covers two years of operation between 2000 and 2002 for each unit and contains descriptions of 2,991 outage events were collected. The entire database in Microsoft Access format is on the accompanying CD to this report and referred to as Appendix C. The summary reports that the Access file will generate are referred to as Appendix D.

4.2 Summary OR Performance

Tables 4.1 and 4.2 summarize the OR statistics calculated from the database by technology group and duty cycle. The technology groups were defined as:

Reciprocating Engines
Group 1: <100 kW
Group 2: 100 - 800 kW
Group 3: 800 kW – 3 MW

Fuel Cells
Group 4: <200 kW

Gas Turbines
Group 5: 500 kW – 3 MW
Group 6: 3 MW – 20 MW
Group 7: 20 – 100 MW

Microturbines
Group 8: <100 kW

Steam Turbines
Group 9: <25 MW

With the exception of Technology Group 4 (fuel cells), all technology groups demonstrated acceptable to very good OR performance. Good performance is generally considered to be 90% availability factor or higher. Fuel cell OR performance was greatly affected by downtime associated with unusually long delays and not related to typical operation. Waiting time for service or replacement parts can have a serious effect. For example, several multi-month outages due to delays in service created an inaccurate representation of fuel cell OR performance. In those specific cases the availability calculated can become more a measure of the service system than the inherent disposition of the equipment to perform.

The project team identified units in all technology groups that met the selection criteria with the exception of Group 8, microturbines. We believe this is due to the fact that units installed and operating by January 2000, the cut-off date for the required two years of operation to be included in this project were either pre-commercial or first generation microturbines. Developers and users would have had to provide data and characterize operational reliability of this class of technology based on units that would not be representative of the products that would ultimately be used in the market. They were justifiably reluctant to participate on this basis. In fact, this effect was seen in the fuel cell data collected and analyzed for this project. The decision was made not to include microturbine data at this time but to structure the database to accommodate the addition of microturbine data at a later date if so desired.

Table 4.1 – Summary Operational Reliability Statistics by Technology Group

Technology Group	n	Availability (%) Avg.	Outage Rate (%)	Outage Factor (%)	Factor (%) Avg.	Between Forced	Mean Down Time (hrs)
1	14	97.93	1.76	0.73	75.11	784.75	13.71
2	8	95.99	1.98	2.47	51.76	1,352.26	50.66
3	18	98.22	0.85	1.12	40.59	3,582.77	27.06
4	15	76.84	22.94	0.92	74.01	2,004.47	369.24
5	11	97.13	2.89	0.99	57.93	2,219.72	65.38
6	21	94.97	2.88	2.39	82.24	1,956.46	68.63
7	9	93.53	1.37	5.14	88.74	3,604.62	75.30
9	25	92.02	2.34	6.01	81.12	5,317.73	292.06
Entire Sample	121	93.09	4.65	2.66	70.23	2,869.83	138.53

Table 4.2 – Summary Operational Reliability Statistics by Duty Cycle

Duty Cycle	Service Factor Range	N	Availability (%) Avg.	Forced Outage Rate (%) Avg.	Scheduled Outage Factor (%) Avg.	Service Factor (%) Avg.	Mean Time Between Forced Outages (hrs)	Mean Down Time (hrs)
Peak	1-10%	14	99.42	0.02	0.58	2.60	456.80	22.21
Cycling	10-70%	26	88.76	10.15	2.16	54.03	2,339.48	383.19
Baseload	>70%	81	93.39	3.69	3.18	87.11	3,457.13	80.10
Entire Sample	0-100%	121	92.62	6.48	1.59	36.86	1,659.54	250.93

The breakdown by duty cycle shows good OR performance by units in all applications. Cycling average data is less impressive than the other duty cycles. This is primarily due to the fact that a number of technology group 4 units fall into this category.

With regard to very low service factor units (e.g., standby units with service factor 3 %), an additional future analysis based on starting reliability may provide improved insights. These units are characterized by approximately 100-300 hours of annual operation and service hours that range from 100 to 200 hours of maintenance and service. They have a very large percentage of their time in the state of reserve standby during which the unit is fully available but not operating. Using the same OR measures as higher service factor may not represent their reliability accurately.

4.3 Reciprocating Engine Performance

Table 4.3 presents the OR summary results for the three reciprocating engine technology groups, including average and range for all OR measures calculated. They all exhibited very good average OR performance.

Table 4.3 – Summary Statistics for Reciprocating Engine Systems

Reciprocating Engines	<100kW			100-800 kW			800-3000 kW		
Number Sampled		14			8			18	
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	96.27	97.93	99.00	84.55	95.99	99.93	91.14	98.22	100.00
Forced Outage Rate (%)	0.86	1.76	3.07	0.00	1.98	5.05	0.00	0.85	6.63
Scheduled Outage Factor (%)	0.26	0.73	1.33	0.07	2.47	14.22	0.00	1.12	3.42
Service Factor (%)	68.20	75.11	79.60	2.06	51.76	95.43	1.50	40.59	91.39
Mean Time Between Forced Outages (hrs)	505.96	784.75	1376.60	361.18	1352.26	4058.71	263.00	3582.77	14755.30
Mean Down Time (hrs)	7.29	13.71	24.21	12.50	50.66	173.05	0.00	27.06	91.91

4.4 Gas Turbine Performance

Table 4.4 presents the OR summary results for the three gas turbine technology groups, including average and range for all OR measures calculated. They all exhibit good OR performance.

Table 4.4 – Summary Statistics for Gas Turbine Systems

Gas Turbines	0.5-3 MW			3-20 MW			20-100 MW		
Number Sampled		11			21			9	
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	88.88	97.13	100.00	88.56	94.97	99.60	86.33	93.53	99.45
Forced Outage Rate (%)	0.00	2.89	18.84	0.00	2.88	9.07	0.00	1.37	6.63
Scheduled Outage Factor (%)	0.00	0.99	4.57	0.00	2.39	11.44	0.00	5.14	13.50
Service Factor (%)	5.33	57.93	97.27	6.26	82.24	99.01	70.27	88.74	99.45
Mean Time Between Forced Outages (hrs)	765.62	2219.72	4318.00	216.77	1956.46	15298.00	536.00	3604.62	17424.00
Mean Down Time (hrs)	0.17	65.38	325.09	2.77	68.63	501.75	21.29	75.30	288.50

4.5 Fuel Cell and Steam Turbine Performance

Table 4.5 presents the OR summary results for the fuel cell and steam turbine technology groups, including average and range for all OR measures calculated. The steam turbine group exhibits slight lower OR performance than the reciprocating engine and gas turbine technology groups. Fuel cell operational reliability indices calculated from our sample were significantly lower than all other technology groups and what fuel cell manufacturers typically quote. Availability, forced outage rate and mean down time was greatly affected by downtime associated with unusually long delays (e.g., maintenance personnel response, availability of replacement parts, site operations) and not related to typical operation.

Table 4.5 – Summary Statistics: Fuel Cells and Steam Turbines

Other Technologies	Fuel Cells <200kW			Steam Turbines <25MW		
Number Sampled		15			25	
	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	42.31	76.84	95.04	72.37	92.02	99.82
Forced Outage Rate (%)	4.31	22.94	57.51	0.00	2.34	16.41
Scheduled Outage Factor (%)	0.48	0.92	1.23	0.00	6.01	27.63
Service Factor (%)	42.27	74.01	92.21	3.37	81.12	99.65
Mean Time Between Forced Outages (hrs)	1416.71	2004.47	2696.33	120.18	5317.73	29585.00
Mean Down Time (hrs)	66.92	369.24	1686.83	5.51	292.06	4848.00

4.6 Comparison to Central Station Operational Reliability Performance

The North American Reliability Council Generating Availability Data Service (NERC GADS) was created to provide utilities with information on OR perfomance of electric generating units and their related equipment. One of the primary reports that NERC GADS produces is the *Generating Availability Report* (GAR). The GAR reports OR data over a cumulative five years, annually. The statistics in the GAR are calculated from data that electric utilities report voluntarily to (NERC GADS). Operating histories for more than 4,400 electric generating units reside in GADS. Data are reported by 178 utilities in the United States and Canada, representing investor-owned, municipal, state, cooperative, provincial, and federal segments of the industry. NERC aggregates these data and presents the results annually in its GAR. Table 4.6 shows 1997-2001 OR performance data for five central station technologies. Data on onsite generation technologies assessed for this project are comparable or better than the most recent NERC GAR OR data on central station technologies.

Table 4.6 NERC GAR 1997-2001 Summary OR Statistics

OR Measure	Fossil (Boiler)	Nuclear	Gas Turbine	Combined Cycle	Hydro
# of Units	1524	128	887	80	823
Availability Factor (%)	86.66	82.87	90.31	85.85	90.62
Forced Outage Rate (%)	5.16	7.83	41.40	3.24	4.68
Scheduled Outage Factor (%)	9.59	10.09	6.36	7.64	6.53
Service Factor (%)	68.98	82.85	4.72	61.36	57.95

5 ASSESSMENT OF EVENT CAUSES

5.1 Outage Event Summary

The project team tabulated the distribution of planned and unplanned (forced) outages for each technology group. Tables 5.1 to 5.8 show the distribution between planned and forced outages and the subsystem to which they were attributed for each technology group. Note that no subsystem codes are assigned for technology group for reasons documented in previous sections of this report.

Table 5.1 - Reciprocating Engine (<100 KW) Outage Statistics

Reciprocating Engines <100 kW	System Component Code	Events	Duration (hrs)
Planned Outage	Controls	12	28.8
	Engine System	109	1,768.80
Planned Outage Total		121	1,797.60
Forced Outage	Controls	103	309.4
	Engine System	29	766
	Generator	19	450
	Heat Recovery System	38	1,117.20
	Ignition System	20	395.9
	Plant Service	35	243.3
	No Record	1	14.8
Forced Outage Total		245	3,296.50
Grand Total		366	5,094.10

Table 5.2 - Reciprocating Engine (100-800 KW) Outage Statistics

Reciprocating Engines 100-800 kW	System Component Code	Events	Duration (hrs)
Planned Outage	Engine System	4	334
	Electrical System	2	21
	Plant Service	6	14
	No Record	45	5472.9
Planned Outage Total		57	5841.9
Forced Outage	Controls	15	258.5
	Engine System	19	527
	Electrical System	3	92
	Fuel System	19	1151
	Heat Recovery System	7	383
	Plant Service	5	53
	No Record	7	414
Forced Outage Total		75	2878.5
Grand Total		132	8720.4

Table 5.3 - Reciprocating Engine (800-3,000 KW) Outage Statistics

Reciprocating Engines 800-3,000 kW	System Component Code	Events	Duration (hrs)
Planned Outage	Controls	3	1.2
	Engine System	69	1161.5
	Electrical System	1	194.3
	Fuel System	1	49
	Plant Service	404	808
	No Record	25	1339.9
Planned Outage Total		503	3553.9
Forced Outage	Controls	10	216.9
	Engine System	16	734
	Electrical System	2	8.3
	Fuel System	6	202.8
	Heat Recovery System	4	264.3
	Plant Service	9	209.2
	No Record	13	446
Forced Outage Total		60	2081.5
Grand Total		563	5635.4

Table 5.4 - Fuel Cell Outage Statistics

Fuel Cells <200 kW	System Component Code	Events	Duration (hrs)
Planned Outage	Not Accounted	101	2699
Forced Outage	Not Accounted	109	56383.8
Grand Total		210	59082.8

Table 5.5 - Gas Turbine (0.5-3.0 MW) Outage Statistics

Gas Turbine 500-3000 kW	System Component Code	Events	Duration (hrs)
Planned Outage	Combustor Section	1	44
	Electrical System	4	54.9
	Gas Turbine System	118	5038.7
	Generator	6	322.5
	Heat Recovery System	2	11.6
	Lube Oil System	3	74.9
	Fuel System	10	63.4
	No Record	62	2293.3
Planned Outage Total		206	7903.3
Forced Outage	Combustor Section	1	41.3
	Controls	64	1285.2
	Electrical System	7	55.8
	Fuel System	82	1085.5
	Gas Turbine System	165	2277.1
	Generator	8	126.3
	Heat Recovery System	20	2195.2
	Inlet Air System	2	33.5
	Lube Oil System	4	6.5
	Plant Service	92	450.3
	No Record	21	811.9
Forced Outage Total		466	8368.6
Grand Total		672	16271.9

Table 5.6 - Gas Turbine (3-20 MW) Outage Statistics

Gas Turbine 3-20 MW	System Component Code	Events	Duration (hrs)
Planned Outage	Controls	7	511.5
	Cooling Water System	1	1.9
	Electrical System	2	145.4
	Emission Controls	3	70.7
	Fuel System	2	3.8
	Gas Turbine System	27	6863.2
	Generator	5	146.8
	Heat Recovery System	6	265.3
	Inlet Air System	1	19
	Lube Oil System	2	10.9
	Plant Service	6	299.9
	No Record	145	10566
Planned Outage Total		207	18904.4
Forced Outage	Controls	20	298.3
	Cooling Water System	1	2.8
	Electrical System	21	1062
	Emission Controls	10	757
	Exhaust System	1	0.3
	Fuel System	25	138.4
	Gas Turbine System	27	72
	Generator	2	80.6
	Heat Recovery System	6	253.3
	Lube Oil System	11	131.7
	Plant Service	25	225.2
	Start Menu	2	0.6
	No Record	55	3785.2
Forced Outage Total		206	6807.4
Grand Total		413	25711.8

Table 5.7 - Gas Turbine (20-100 MW) Outage Statistics

Gas Turbine 20-100 MW	System Component Code	Events	Duration (hrs)
Planned Outage	Controls	3	438
	Electrical System	5	38.2
	Fuel System	1	6.3
	Gas Turbine System	17	1595.3
	Heat Recovery System	3	105.8
	Plant Service	18	420.1
Planned Outage Total		47	2603.7
Forced Outage	Controls	2	126
	Electrical System	2	6.3
	Fuel System	2	28.8
	Gas Turbine System	4	39.3
	Generator	2	102.7
	Plant Service	19	872.4
	No Record	2	1304.5
Forced Outage Total		33	2480
Grand Total		80	5083.7

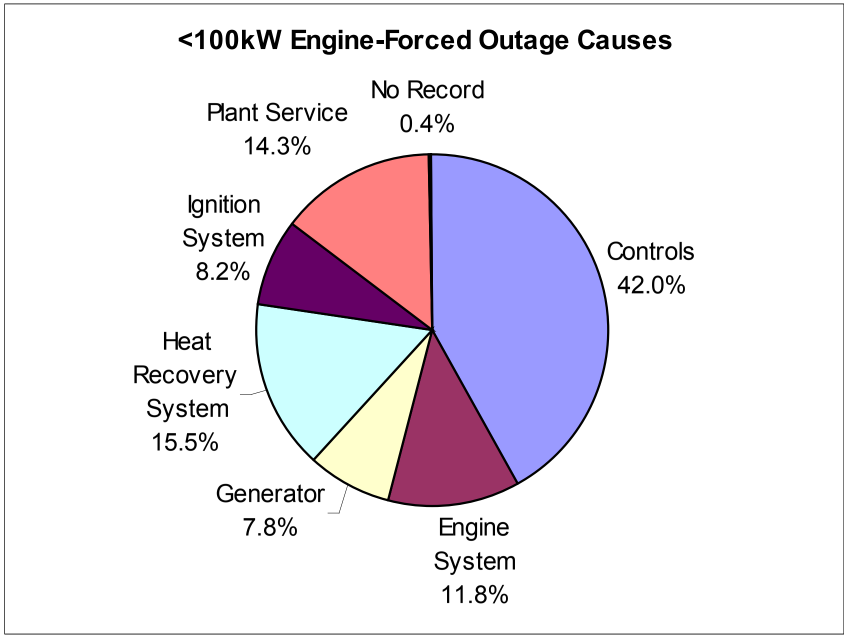
Table 5.8 - Steam Turbine (<25 MW) Outage Statistics

Steam Turbine <25 MW	System Component Code	Events	Duration (hrs)
Planned Outage	Boiler	15	2163.9
	Controls	23	3816.3
	Cooling Water System	2	31.6
	Electrical System	1	175
	Exhaust System	1	5
	Feed Water System	3	6.5
	Fuel System	11	56
	Generator	15	735.5
	Lube Oil System	3	257.8
	Plant Service	22	2017.3
	Steam Turbine System	22	10270.8
	No Record	115	12997.8
Planned Outage Total		233	32533.5
Forced Outage	Boiler	9	704.4
	Controls	29	259.6
	Cooling Water System	4	202.6
	Electrical System	13	991.5
	Exhaust System	4	27.9
	Feed Water System	5	20.1
	Fuel System	22	171.2
	Generator	16	2274.3
	Lube Oil System	3	9
	Plant Service	137	1623.8
	Steam Turbine System	55	2431.8
	No Record	22	455.3
Forced Outage Total		319	9171.5
Grand Total		552	41705

5.2 Forced Outage Assessment by Subsystem

OR data was analyzed in order to characterize the contributions of subsystems to forced outages. Figures 5.1 to 5.7 depict the outage event occurrence percent contribution and outage downtime percent contribution to forced outages by subsystem. Technology group 4 data is not present as cause of event data could not be accurately accounted due to reasons noted previously in this report.

Figure 5.1 - Outage Causes as a Percent of Occurrences and Total Downtime: <100 KW Engine Systems



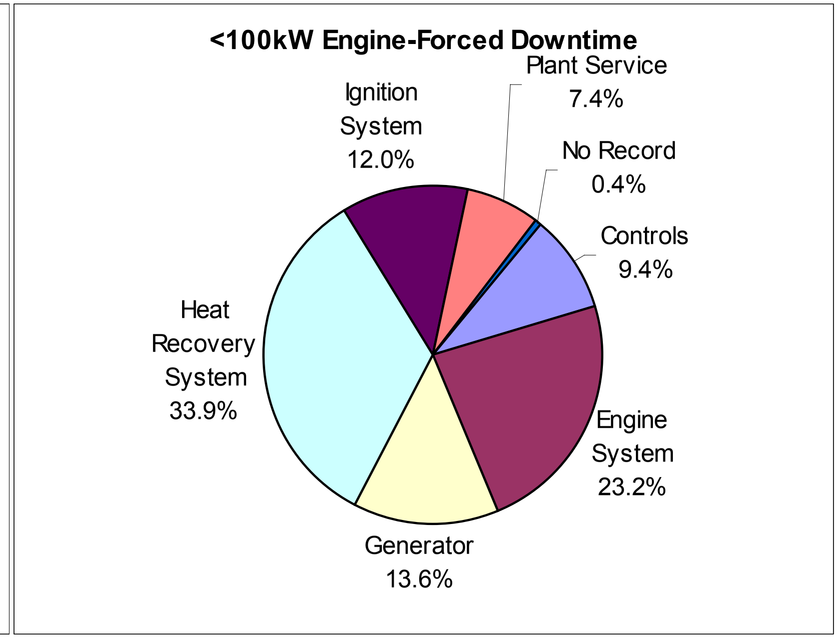
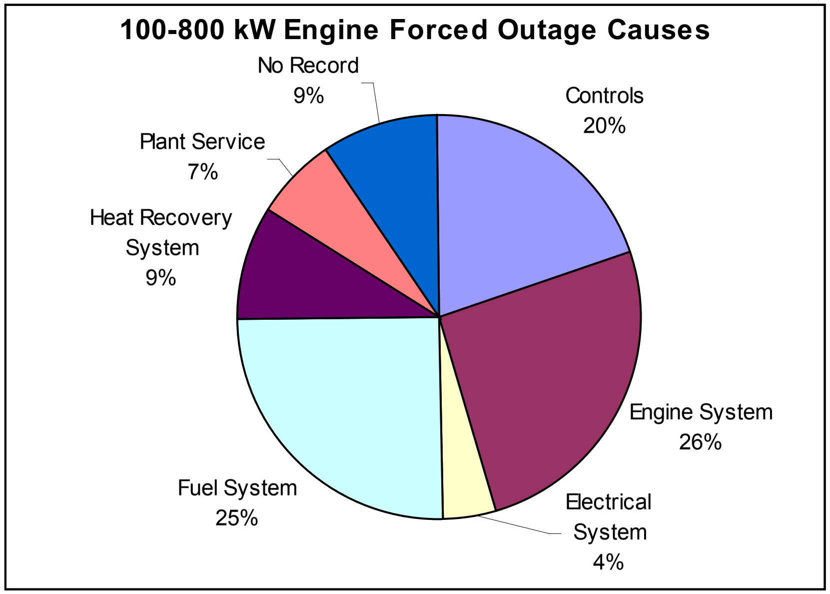


Figure 5.2 - Outage Causes as a Percent of Occurrences and Total Downtime: 100-800 KW Engine Systems



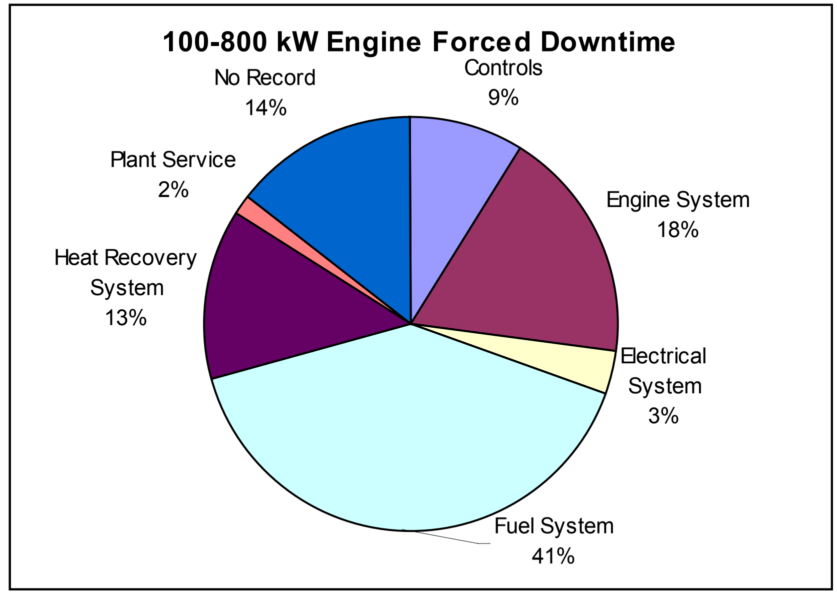
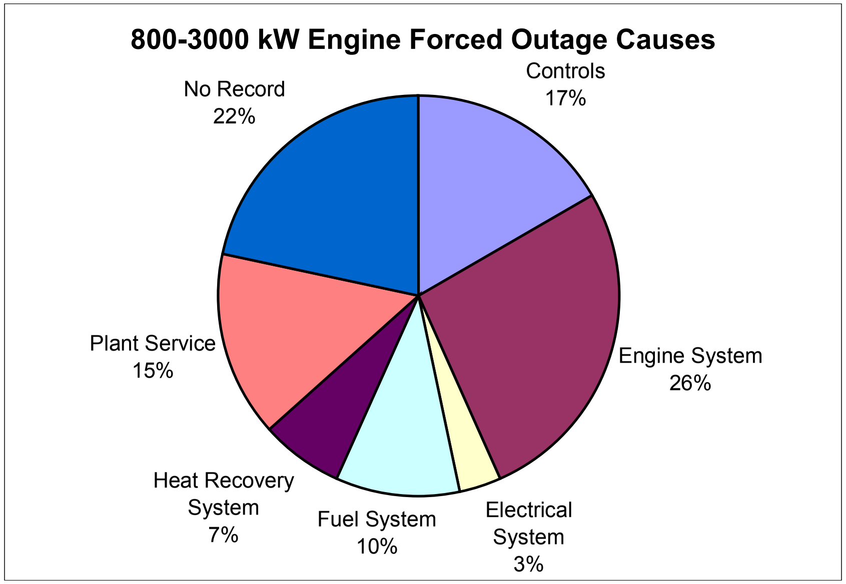


Figure 5.3 - Outage Causes as a Percent of Occurrences and Total Downtime: 800-3,000 KW Engine Systems



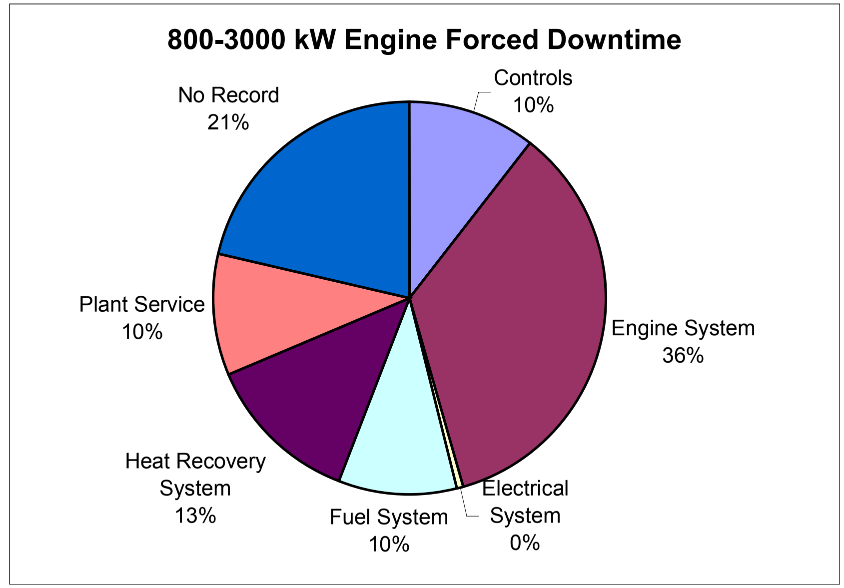
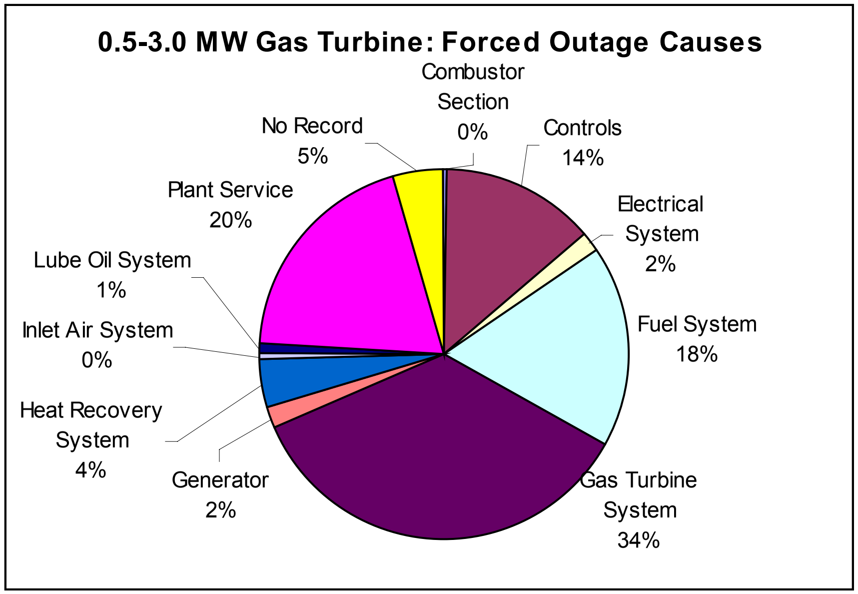
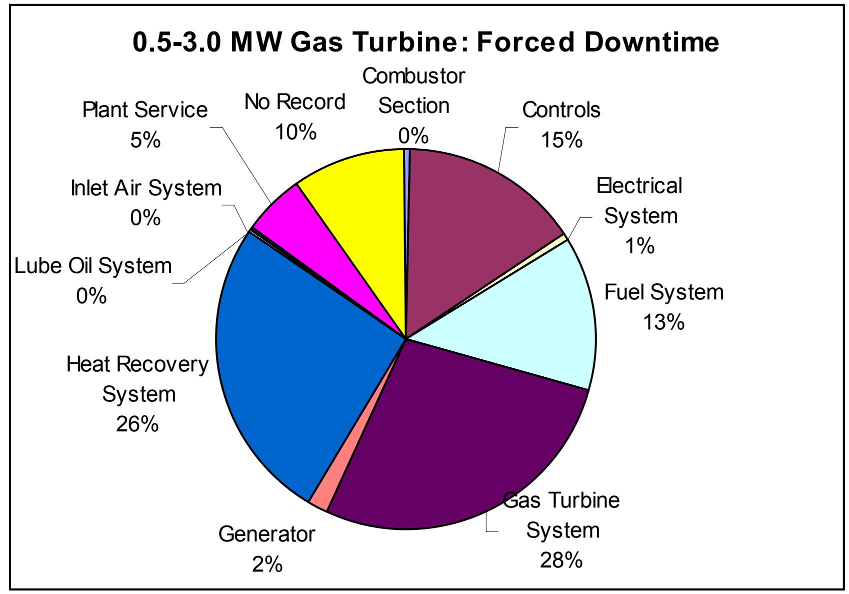


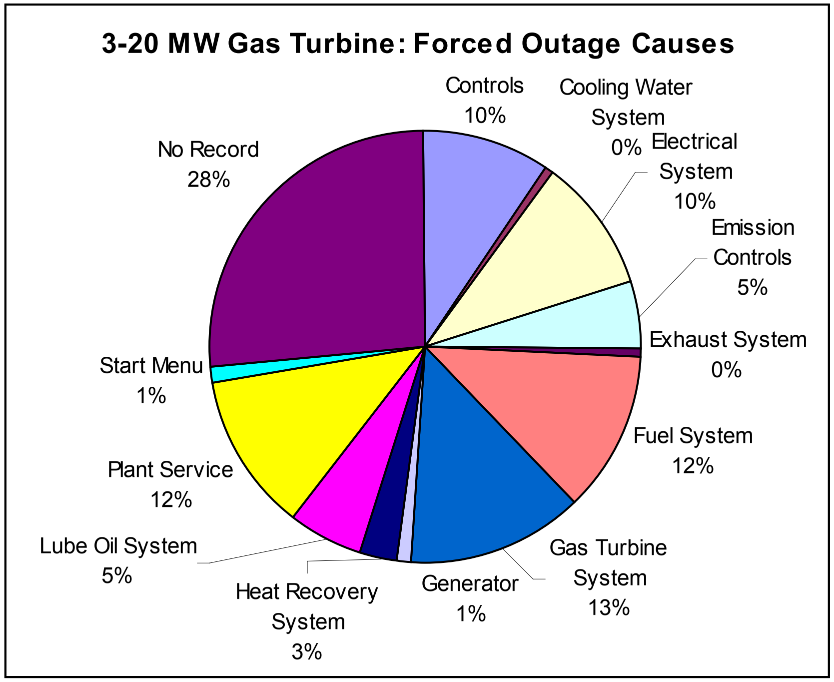
Figure 5.4 - Outage Causes as a Percent of Occurrences and Total Downtime: 0.5-3.0 MW Gas Turbine Systems

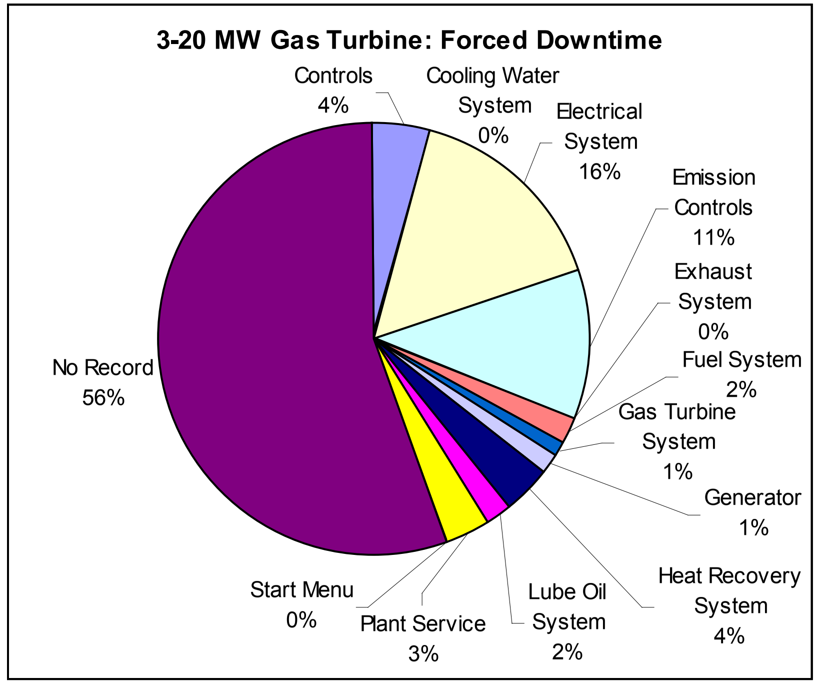




Note that in the case of the 0.5-3.0 MW gas turbine group that two forced outages on a single unit accounted for 1961 hours of forced downtime attributed to Heat Recovery System (extended derate, HRSG inspection, tube leak and repair) or 94% of all downtime due to Heat Recovery System.

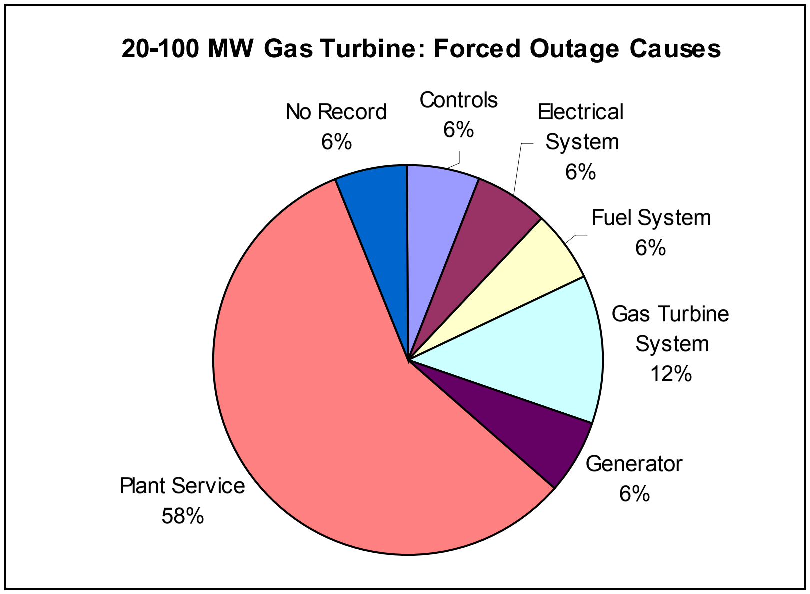
Figure 5.5 - Outage Causes as a Percent of Occurrences and Total Downtime: 3-20 MW Gas Turbine Systems





Note that in the case of the 3-20 MW gas turbine group that a single forced outage on one unit accounted for 155.7 hours of forced downtime attributed to Heat Recovery System or 61% of all downtime due to Heat Recovery System.

Figure 5.6 - Outage Causes as a Percent of Occurrences and Total Downtime: 20-100 MW Gas Turbine Systems



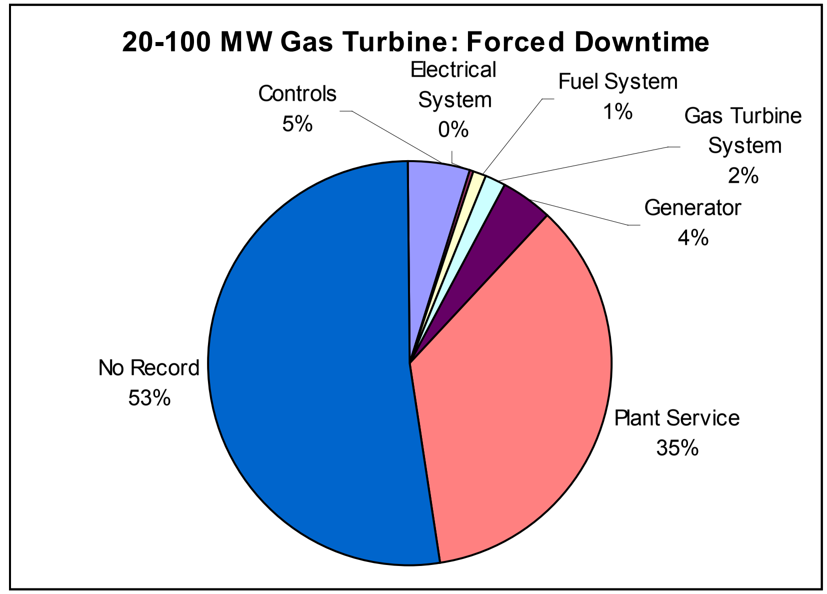
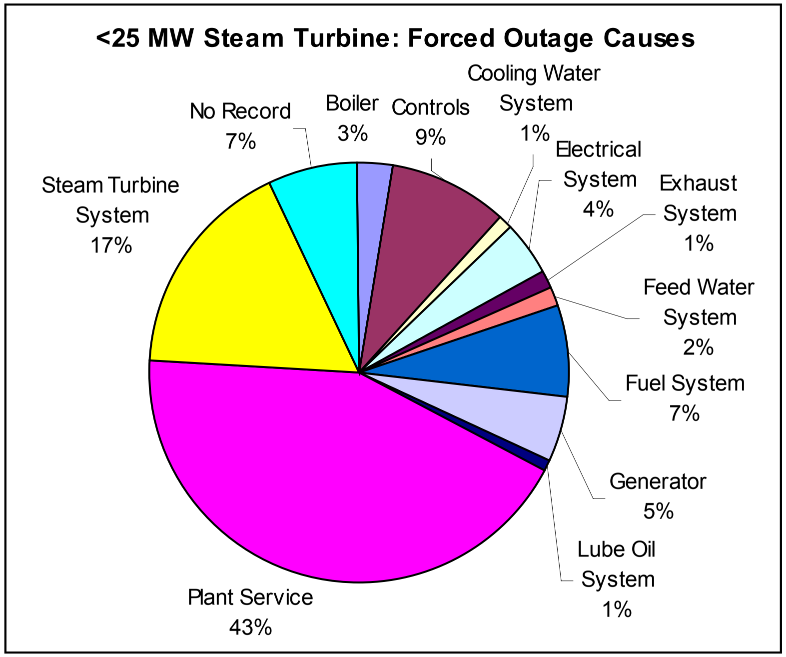
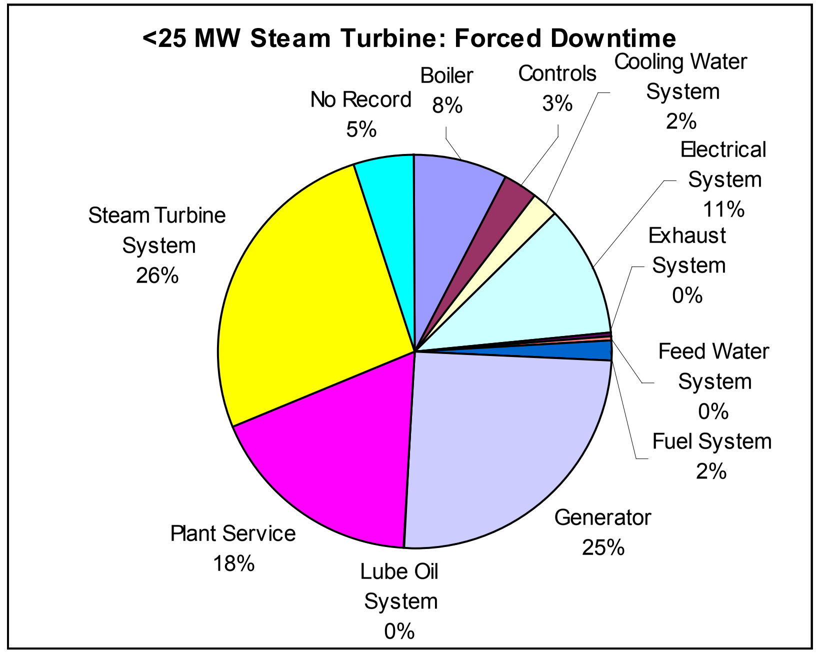


Figure 5.7 - Outage Causes as a Percent of Occurrences and Total Downtime: <25 MW Steam Turbine Systems





6 CONCLUSIONS

6.1 Introduction

Demonstrated acceptable levels of DG/CHP system operational reliability (OR) performance is a critical element in market development. This project represented the first attempt to establish baseline operating and reliability data for DG/CHP systems in more than a decade. The database framework established is a solid foundation for continued data collection and analysis of OR performance of onsite generation technologies.

The entire project methodology was based heavily on the involvement of DG/CHP users. Data (maintenance logs, operation records, and other available sources) and results came directly from actual customer operating data and experience. This required an extremely labor-intensive effort on the part of both project participants and the project team. The voluntary cooperation of participating facilities and time assembling data and being interviewed was greatly appreciated. While time-intensive the involvement of users created better understanding of actual operations.

6.2 Discussion of Results

The DG/CHP units in our database sample demonstrated on average good OR performance. The OR measures calculated were comparable to or better than OR performance of central station technologies. The use of multiple units at sites can undoubtedly result in very-high levels of availability.

During the course of the project, specific units were observed to exhibit both very good to poor OR performance. In almost all technology groups, subsystems other than the prime movers themselves contributed significantly to occurrence of forced outage events. Many events that occur are the result of random equipment failures expected of any complex power system. Other events may be nonrandom in nature, indicating problems that may relate to issues pertaining to the unit design or installation. This project did not result in the identification of any such systemic problems. Most failures within technology groups appear to be random occurrences of short duration.

It is noteworthy that OR performance of established commercial technologies (i.e., reciprocating engines and gas turbines) was significantly better than the sample of emerging technologies (fuel cells) included in the project. Fuel cell operational reliability indices calculated were significantly lower than all other technology groups and what fuel cell manufacturers typically quote. Availability, forced outage rate and mean down time were greatly affected by downtime associated with unusually long delay (e.g., maintenance personnel response, availability of replacement parts, site operations) and not related to typical operation. It would be unfair to attribute downtime to equipment that is more appropriately attributed to the developing nature of the service system. The OR performance of emerging technologies and early commercial products need to be compared separately. Established products have the benefit of millions of hours of operation from which to develop operations and maintenance best practices. Their observed performance in this project and prior work bears this out. As time passes and more experience is gained from the operation of emerging technologies, it is likely their demonstrated OR performance will improve to the level of the other technologies.

With regard to the database itself, it is intended to establish a baseline of OR data on DG/CHP and allow current and potential users to benchmark reliability. The methodology and framework for recording and analyzing data is straight forward, repeatable and consistent with industry standards. It should be noted that the data reviewed for this project is only for the 2000-2002 time period. The database does not include large samples in all technology groups. It is structured to accommodate more units and technology groups in a follow-on effort. Future periodic updating and maintenance on a regular basis will ensure continued usefulness and increase the confidence in the measures calculated.

6.3 Recommended Follow-on Activities

The first version of the DG/CHP Reliability and Availability Database provides a general framework for recording operating data and analyzing OR performance. It provides a solid foundation for future improvements and enhancements. Recommended improvements to the database framework include:

- Adding additional units to improve the robustness of the data
- Annual updating of data to include years of operation beyond the original 2000-2002 period
- Include microturbines with at least two years of operations (not including R&D demonstration) along with fuel cells with similar operating history in a separate database pertaining to emerging DG/CHP technologies
- Conduct starting reliability analysis on very low service factor standby units

Any follow-up effort needs an efficient site identification and data collection process. For example, monthly data submission by site operators with secure web-based data entry system would reduce the labor costs associated with data collection substantially.

7 REFERENCES

1. *Reliability of Natural Gas Cogeneration Systems*, GRI report 93/0020, Gas Research Institute, 1992.

2. *FOREMAN Software User Guide – An Operations and Maintenance Data Manager and Reliability Reporting System*, Gas Research Institute, 1993.

3. *Recommended Practice for Design of Reliable Industrial and Commercial Power Systems*, IEEE Standard 493-1997, Institute of Electrical and Electronics Engineers, 1998

4. *Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity*, ANSI/IEEE Standard 762, Institute of Electrical and Electronics Engineers, 1988

5. *Reliability Survey of 600-1800 kW Diesel and Gas-Turbine Generating Units*, Smith, C.A., Donovan, M.D., Bartos, M.J., IEEE ICPSD 89-02, Institute of Electrical and Electronics Engineers, 1988.

6. *Reliability Measurements for Gas Turbine Warranty Situations*, Ekstrom, T.E., ASME 92-GT-208, American Society of Engineers, 1992.

7. *1997-2001 Generating Availability Report*, North American Reliability Council/Generating Availability Data System, 2002.

APPENDIX A CANDIDATE SOLICITATION LETTER

Dear Developer/Manufacturer/Operator of Distributed Generation Facilities:

On behalf of the U.S. Department of Energy and Oak Ridge National Laboratory, Energy Nexus Group, a subsidiary of ONSITE Energy, is writing to make you aware of a contract recently awarded to us regarding reliability of distributed generation systems and to inquire about your willingness and ability to participate in this worthwhile project.

We hope you find value in participating in this worthwhile project. The project focuses on the development of a specific information tool to help accelerate the development of the industrial Distributed Generation (DG) market: an operational reliability and availability database for on-site generation technologies. We are seeking your assistance in identifying onsite generation sites with at least two years of operating experience to populate the database. The US DOE has identified the need for improved information on industrial DG system reliability and availability as one of several critical elements in fostering the DG market.

The final work product will be a database of operational reliability data for DG systems. The database will allow individual DG facility managers to better understand reliability and availability performance of their particular units and also determine how their facilities compare with other DG resources. Detailed information on DG reliability and availability performance will enable potential DG users to make a more informed purchase decision, and will help policy makers quantify potential grid system benefits of customer-sited DG. For example, the reliability information can be used as an advocacy tool in working with regulators on reasonable standby power rates and backup charges.

The methodology for assessing the operational reliability of DG systems will be to initially establish baseline operating and reliability data for industrial distributed generation systems through an exhaustive collection of data from a representative sample of operating facilities. Information will be gathered from maintenance logs, operation records, manufacturers' data, and other available sources. The project team will then identify and classify DG system failures and outages for various types of technology, fuels and applications. A failure mode analysis will provide insight into system failure modes and causes, and quantify system downtimes for planned and unplanned maintenance.

We are currently in the process of identifying and screening potential sites to populate the database and could use your assistance. In developing our technical approach we recognized that the operational reliability performance data base must address diverse prime mover technologies and applications, the calculated performance statistics must be statistically meaningful, and the procedures for collecting, processing, and analyzing data must be tightly controlled. To that end, we have developed the following general criteria for screening potential sites for inclusion in the database.

- Minimum of two years of operating service
- Completeness of O&M data
- Willingness to allow the project team to review O&M data
- Representative of the technology and prime mover population as a whole
- O&M Practice (e.g., in-house or contracted maintenance, continuous or cycling)
- Geography
- Customer sector

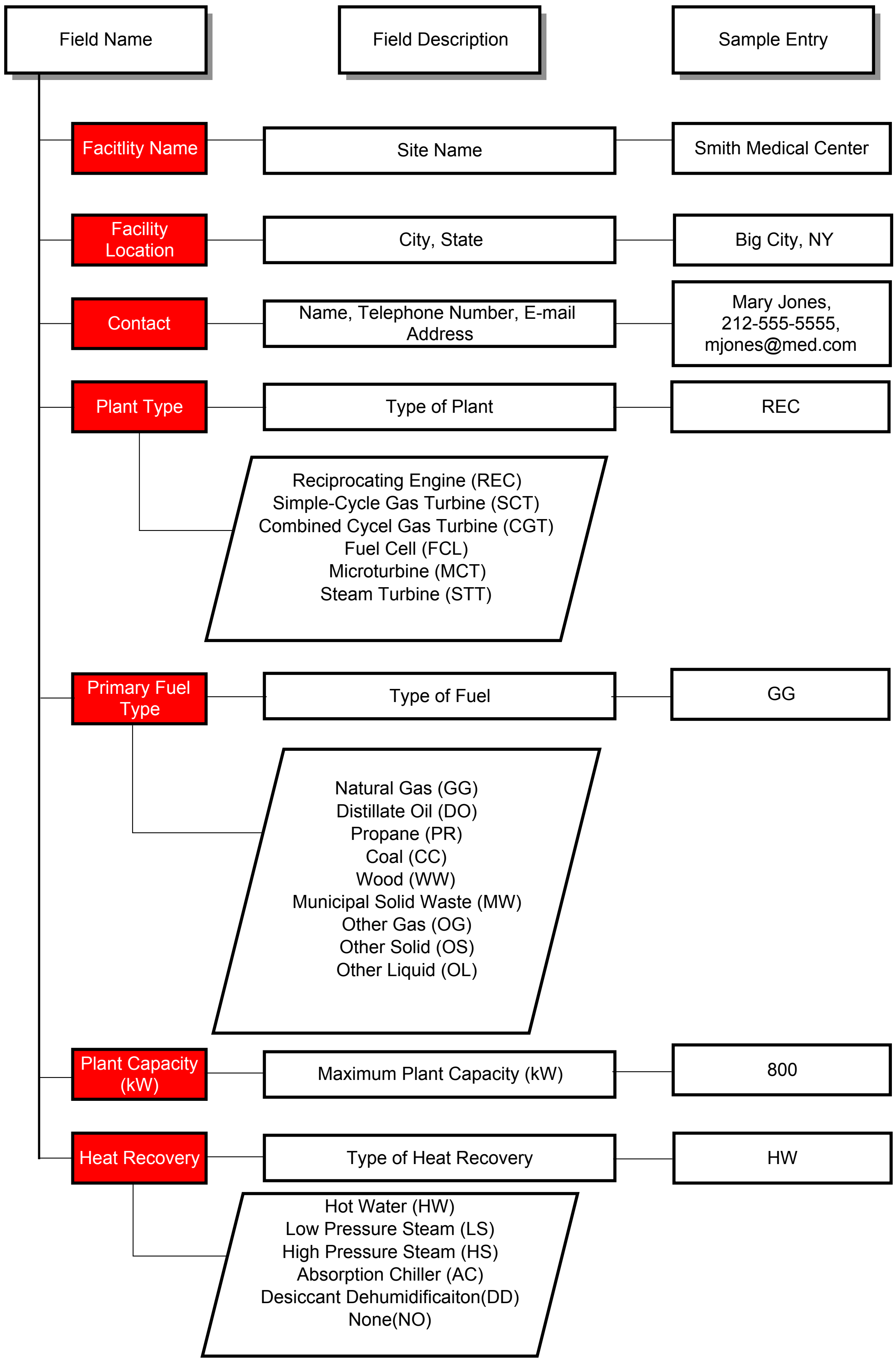
Again, it is envisioned that the final work product of this project will allow for better understanding of reliability and availability performance of particular DG technologies and determine how facilities compare with other DG resources. The results will also allow for improved financial analyses to be conducted with better understanding of operational and financial impacts of unavailability, likely unplanned outages, and other service interruptions.

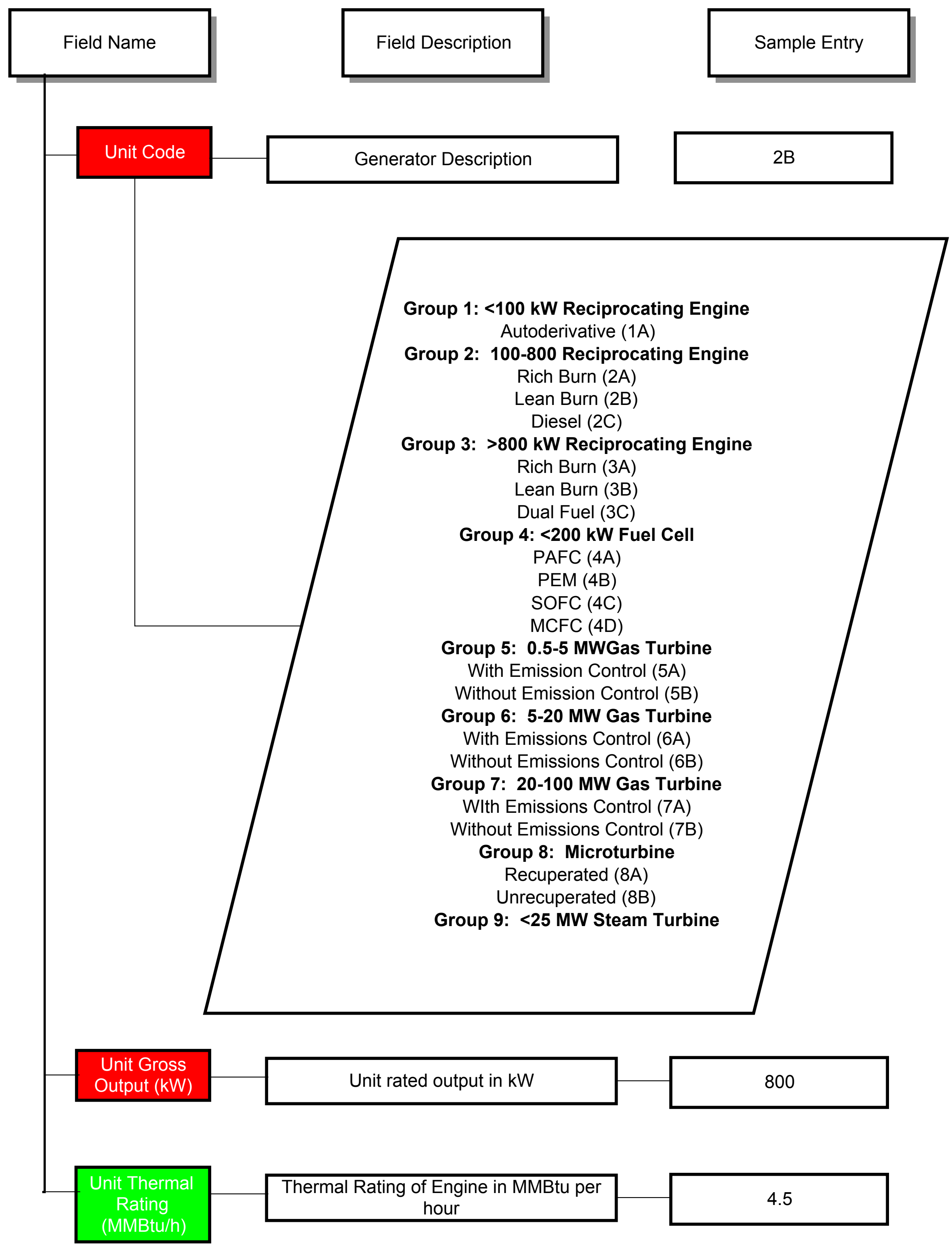
If you have sites in mind that would be good candidates for inclusion in the database please contact me. In the meantime, you may be contacted by a member of the project team regarding your participation and with a more detailed set of questions regarding participating and the screening criteria for inclusion in the final database.

Thank you for your time and consideration.

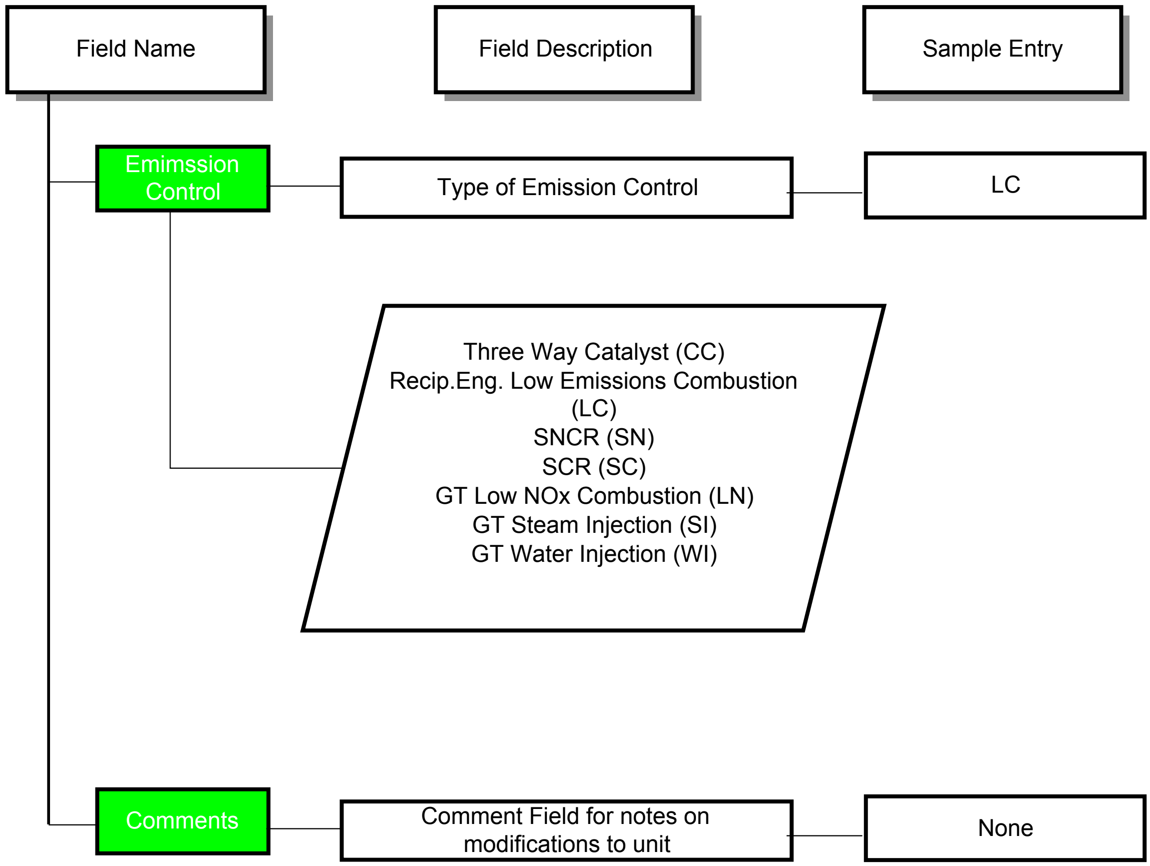
APPENDIX B DATA COLLECTION AND MANAGEMENT SOFTWARE STRUCTURE AND USER GUIDE

Facility/Plant Information




Field Name
Field Description
Sample Entry
Unit Code
Generator Description
2B
Group 1: <100 kW Reciprocating Engine
Autoderivative (1A)
Group 2: 100-800 Reciprocating Engine
Rich Burn (2A)
Lean Burn (2B)
Diesel (2C)
Group 3: >800 kW Reciprocating Engine
Rich Burn (3A)
Lean Burn (3B)
Dual Fuel (3C)
Group 4: <200 kW Fuel Cell
PAFC (4A)
PEM (4B)
SOFC (4C)
MCFC (4D)
Group 5: 0.5-5 MWGas Turbine
With Emission Control (5A)
Without Emission Control (5B)
Group 6: 5-20 MW Gas Turbine
With Emissions Control (6A)
Without Emissions Control (6B)
Group 7: 20-100 MW Gas Turbine
WIth Emissions Control (7A)
Without Emissions Control (7B)
Group 8: Microturbine
Recuperated (8A)
Unrecuperated (8B)
Group 9: <25 MW Steam Turbine
Unit Gross Output (kW)
Unit rated output in kW
800
Unit Thermal Rating (MMBtu/h)
Thermal Rating of Engine in MMBtu per hour
4.5

Unit Information continued (needed for each unit at facility)

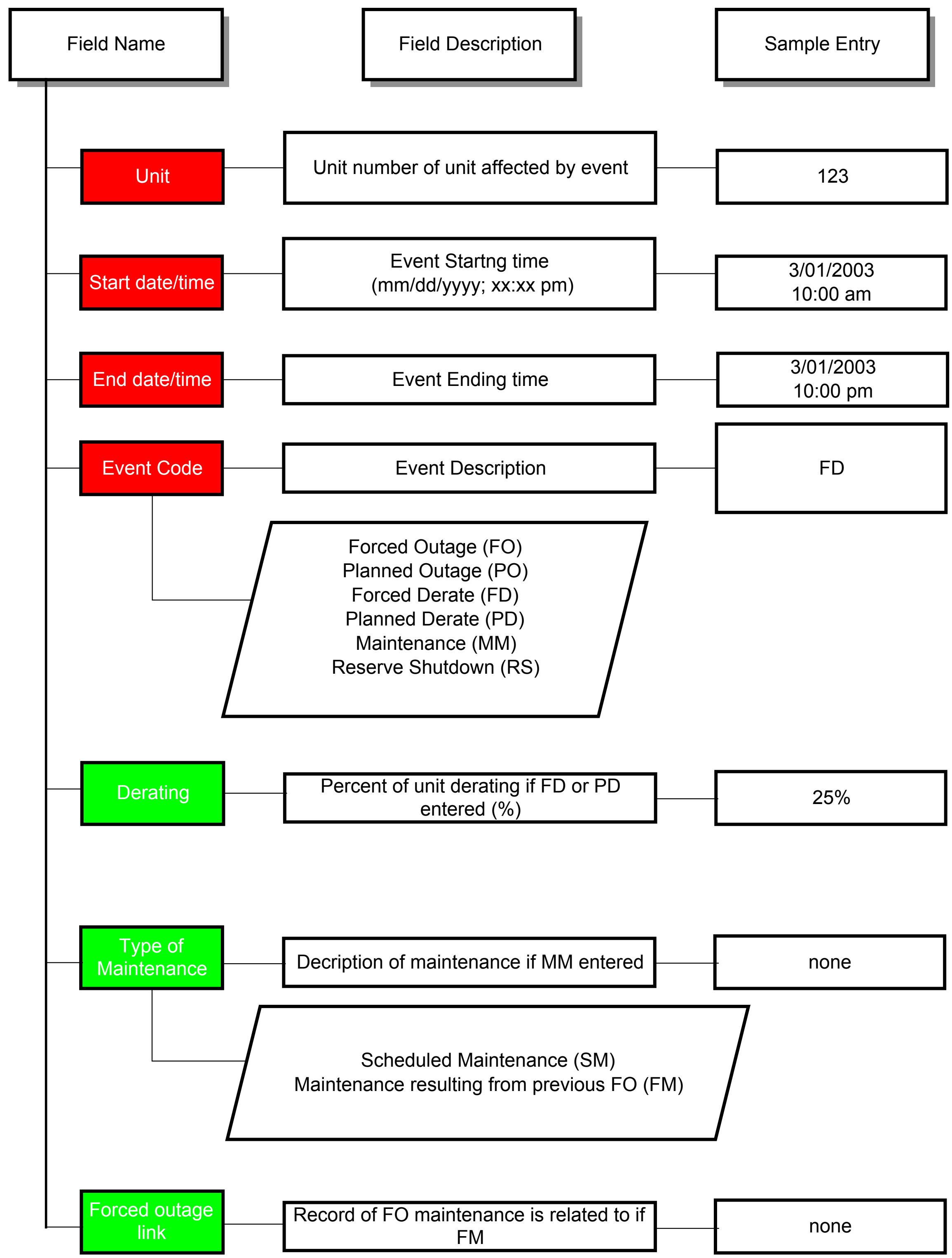


A unique record number for each facility and unit will be assigned

Monthly Generation History (needed for each unit)

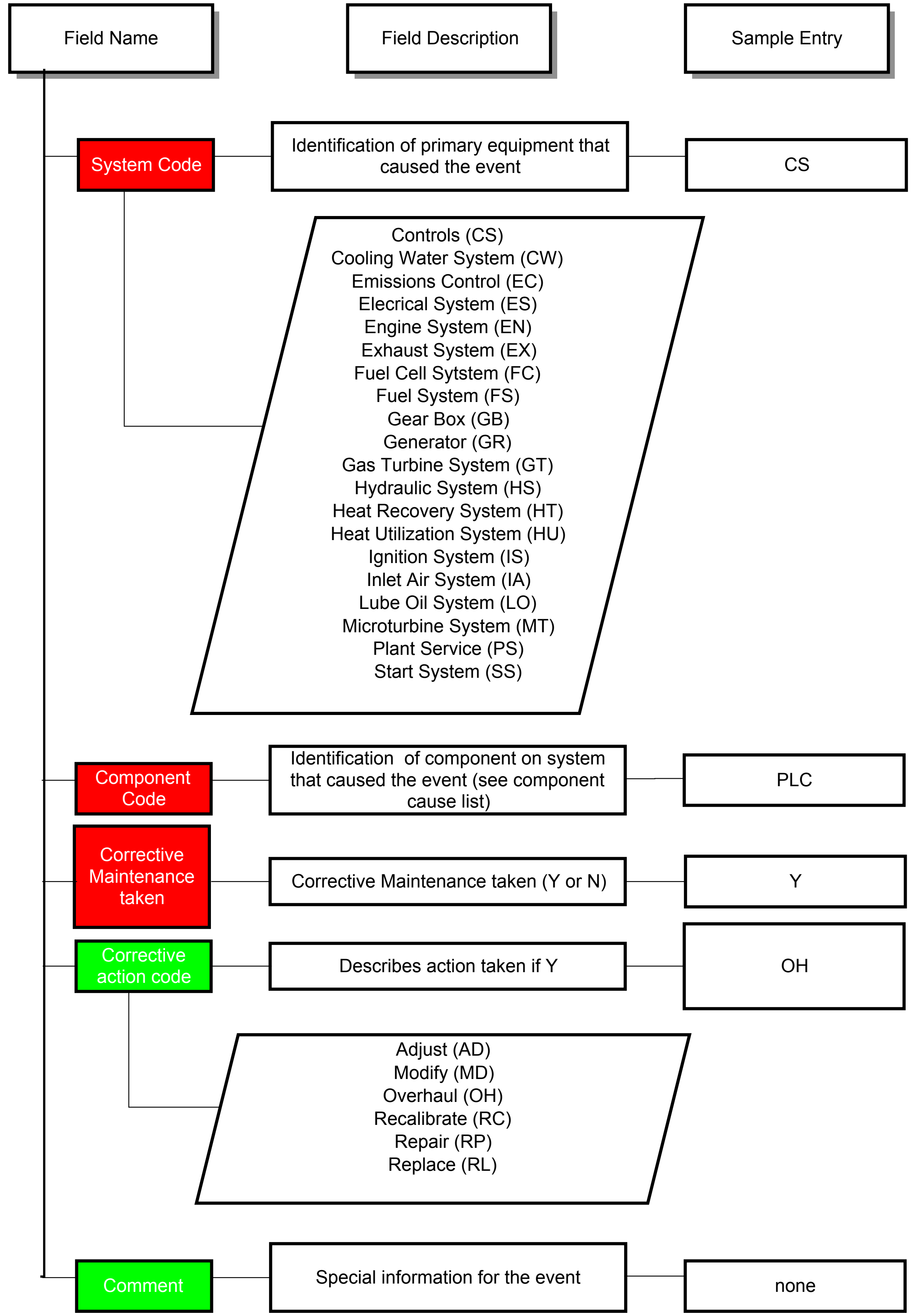
Field Name	Field Description	Sample Entry
Unit Record Number	Unique number assigned to each unit	123
Month	Date (MM/YYYY)	10/2003
Total Service Hours	Total run hours at any output (hrs)	700
Number of Attmepted Starts	Number of starts attempted to bring the unit from shutdown to synchronizations. Repeated failure to start for the same cause without a corrective action is considered a single attempt.	4
Number of Successful Starts	Number of times the unit successfully started and sychronized	3

Event Log Data



Each event for every unit will be assigned an event record number (e.g., 1,2,3...)

Event Log Data continued



Component Cause List

Controls
Microprocessor
Data Logger
Modem
Power Supply
Overspeed Board
Control Cards
Relay Input Board
Governor Board
Analog Temp Board
Distributed Control System (DCS)
Panel Devices
Software Error
Programmable Logic Controller
Multiplexer
Local Area Network
I/O Module
Slave Module
Termination Unit
Unknown Trip

Cooling Water System
Pump
Radiator
Coolant
Belt
Transducer
Radiator Cap
Hose
Flow Switch
Piping
Pressure Switch
Gauges

Emissions Control
Catalyst
Piping/Ductwork
Water Injection System
Steam Injection System
SCR System
Engine LEC
GT LNC
SNCR
Instrumentation/Controls
Compliance Testing

Electrical System
Instrumentation
Battery
Governor
Circuit Breaker
Power Supply
Wires/Fuses
Stepper Motor
Meters
Distribution
Battery Cable
Relay
Main Fuse

Engine System
Heads
Valve Train
Timing Gear
Crankshaft
Pistons
Connecting Rods
Inlet Manifold
Bearings
Cylinders
Flywheel
Camshaft
Gaskets
Engine Block
Freeze Plugs
Ring Gear
Vibration Switch
Rings
Turbocharger
Aftercooler
Temperature Switch
Gauges
Pressure Switch
Engine Overhaul

Exhaust System
Silencer
Piping
Gaskets
Exhaust Heat Exchanger
Instrumentation/Wiring
Ducting

Fuel Cell System
Fuel Processor
Fuel Quality Monitor
Reformer Inspection
Planned Stack Replacement
Stack Inspection
Stack Temperature Monitor
Fire Detection
Voltage Decay Monitor
Vibration Monitor
Power Electronics
Inverter
Utility Interface
Instrumentation/Wiring
Planned Overhaul

Fuel System
Pressure Regulator
Carburetor
Piping and Valves
Separator
Gas Pump
Prechamber Valves
Fuel Injectors
Fuel Nozzles
Instrumentation/Wiring

Gear Box
Gear Train

Cooler
Oil System
Accessory Drive

Generator
Induction Generator
Bearings
Couplings
Synchronous Generator
Cooling System
Contactor
Instrumentation/Wiring
Excitator
Overhaul

Gas Turbine System
Compressor Section
Combustor Section
Turbine Section
Exhaust Section
Couplings or Clutches
Water Washing
Combustor Inspection
Turbine Section Inspection
Main Bearings
Fuel Nozzle
Transition Pieces
Combustor Seals
Inlet Guide Vanes
Turbine Sealing
Fire Detection System
Inlet Air System
Vibration Monitor
Temperature Monitor
Instrumentation/Wiring
Overhaul

Hydraulic System
Pumps
Piping and Valves
Instrumentation/Wiring
Heat Exchanger
Temperature Regulator

Heat Recovery System
Engine Coolant Heat Exchanger
Pumps and Piping
Pressure Relief Valve
Pressure Regulator Valve
Electronic Controls
Instrumentation/Wiring
Hot Water Heat Recovery Unit
Low Pressure Steam Heat Recovery Unit
High Pressure Steam Heat Recovery Unit
Expansion Tank
Cleaning
Economizer
Superheater
Evaporator
Steam Drum
Structures
Electronic Controls

Duct Burner
Dampers/Duct Work
Inspections/Cleaning
Feedwater System
Boiler Feed Pump
Dearator
Valves/Piping
Instrumentation/Wiring
Sootblower

Heat Utilization System
Steam Condenser
Absorption Chiller
Cooling Tower
Valves
Pumps
Instrumentation/Wiring
Vents
Piping
Steam Turbine

Ignition System
Wiring
Spark Plugs
Distributor
Coil
Ignitor

Inlet Air System
Filter
Fan Bearing
Fan Belt
Fan Motor
Fan Shaft
Silencer
Hose
Ductwork
Guidevanes

Lube Oil System
Filter
Oil Add or Change
Pressure Control
Pump
Cooler
Temperature Regulator
Pressure Regulator
Instrumentation
Wiring
Sump
Piping/Seals
Precipitator

Microturbine System
Controls
Heat Exchanger
Recuperator
Bearing
Gas Compressor
Vibration Monitor
Fuel Nozzle
Dampers/Ducting

Turbomachinery

Plant Service
Gas Utility
Electric Utility
Host Facility

Start System
Electric Starter
Battery
Power Supply
Relay
Pneumatic Starter
Air Starting Valve
Piping

DG Reliability Survey Tool

User Guide

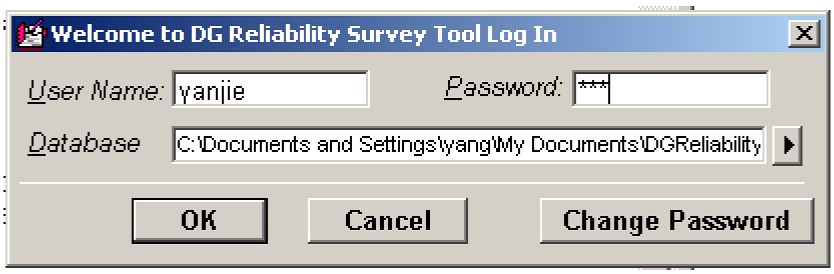
Version 1.0

March 2002

By

Gas Technology Institute
1700 South Mount Prospect Road
Des Plaines, IL 60018

Log-in Interface



The user Log-in form is designed to provide the DG Reliability Survey Tool (DGRST) database security and protect from unauthorized database modification/entries.

Login Commands

Ok command

Use **OK** command to log in the DGRST application after password validation.

Cancel command

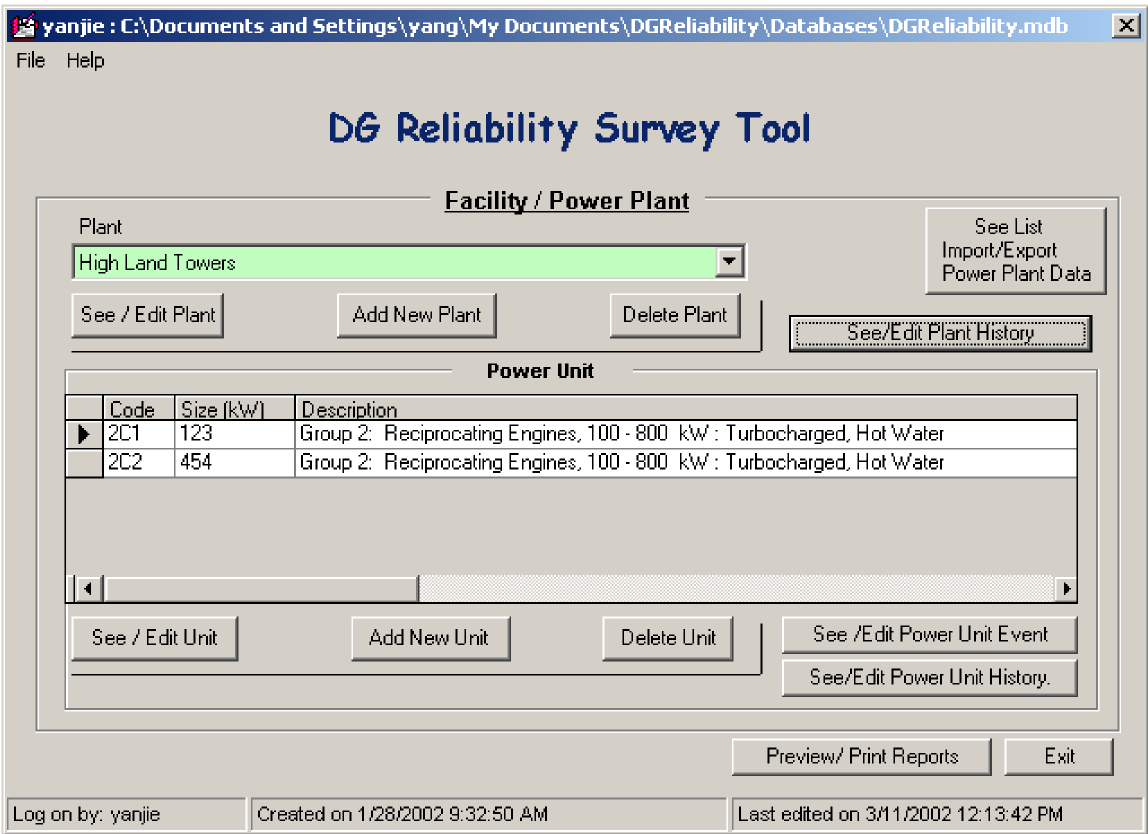
Use **Cancel** command to quit the DGRST application.

Change Password command

Use **Change Password** command to change current user's password after logging in the DGRST application with password validation

DG Reliability Survey Tool (DGRST)

The Main interface provides users with options to select, review, edit, add, delete, import and export plant specific segment of DGRST database.



File Menu

Open command (File menu)

Use the **Open** command to open a new Database Back-end.

Exit command (File menu)

Use the **Exit** command to exit the DGRST application.

Help Menu

Contents command (Help menu)

Use the **Contents** command to call up the DG Reliability Survey Tool Online Help Index. Using this index as a starting point, you can quickly find any Help topic of interest. Once in online Help, you can always return to the main window by clicking the Contents button in the upper left corner of the Help window.

About command (Help menu)

Use the **About** command to find the version number and other pertinent information about DG Reliability Survey Tool.

See / Edit Plant command

Use the **See / Edit Plant** command to be prompted to review or edit the related general information for Facility/plant on the form of **Error! Bookmark not defined.**

Add New Plant command

Use the **Add New Plant** command if you need to add a new facility / plant name. When you choose the Add New Plant command, you will be prompted to specify a new Facility name and location and the related general information on the form of **Error! Bookmark not defined.**

.

Deleted Plant command

Use **Delete Plant** command if you need to delete the facility /plant from the DGRST database**.** **Warning**: once completion of the command, all the facility related information on units, events, and history data will be deleted and can not be undone.

See/Edit Plant History command

Use the **See/Edit Plant History** command to be prompted to review all the plant Monthly History Data on the form of **Error! Bookmark not defined.**

See List /Import/Export Power Plant command

Use the **See List /Import/Export Power Plant** command to be prompted to review the list of all plants in the DGRST database on the form of **Error! Bookmark not defined.**.

See / Edit Unit command

Use the **See / Edit Unit** command to be prompted to review or edit the related general information for the unit on the form of **Error! Bookmark not defined.** One unit should be highlighted from the unit list before clicking on the command.

Add New Unit command

Use the **Add New Unit** command if you need to add a new facility / plant name. When you choose the Add New Unit command, you will be prompted to specify a new unit description and the related information on the form of **Error! Bookmark not defined.**.

.

Deleted Unit command

Use **Delete Unit** command if you need to delete the unit from the DGRST database**.** One unit should be highlighted from the unit list before clicking on the command. **Warning**: once completion of the command, all the unit related information on events and history data will be deleted and can not be undone.

See / Edit Power Unit History command

Use the **See / Edit Power Unit History** command to be prompted to review all the Unit Monthly History Data on the form of **Error! Bookmark not defined.** One unit should be highlighted from the unit list before clicking on the command.

See / Edit Power Unit Event command

Use the **See / Edit Power Unit Event** command to be prompted to review all the events for the unit on the form of **Error! Bookmark not defined.** One unit should be highlighted from the unit list before clicking on the command.

Preview/Print Reports command

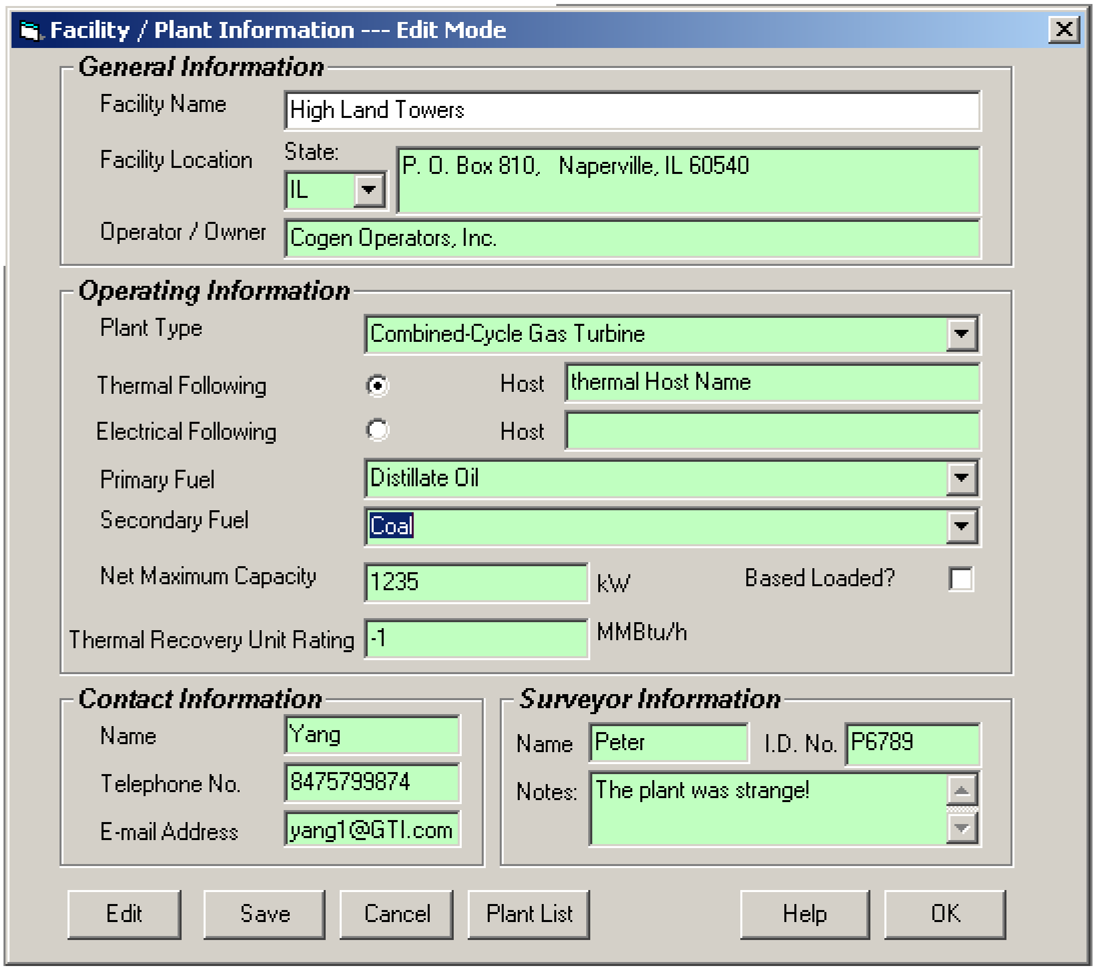
Use the **Preview / Print Reports** command to be prompted to specify reports which you need to preview/print on the form of **Error! Bookmark not defined.**. Plant and /or Unit should be selected before clicking on the command.

Exit command

Use the **Exit** command to exit the DGRST application. It has the same functionality as the Exit command on the File menu.

Facility / Plant Information

Once the plant is selected, related general information can be reviewed / edited. This screen also provides fields to enter contact person and surveyor information.



<u>Facility / Plant Information Commands</u>

Edit command

Use **Edit** command to change the form into the editable mode. The data in the box with light green color can be edited directly. After Edit command executing, Save command will be enabled for saving the update data, and Close command will change to OK command for saving the update data and closing the form.

Save command

Use **Save** command to save all the data on the form. After Save command executing, the form change back to un-editable mode. The back color in data boxes will be light yellow, which means non-editable and only for display. The form changes back as the initial status, non-editable.

Cancel command

Use **Cancel** command to close the form, without saving any update data.

Plant List command

Use **Plant List** command to be prompted to review the list of all plants in the DGRST database on the form of **Error! Bookmark not defined.**

Help command

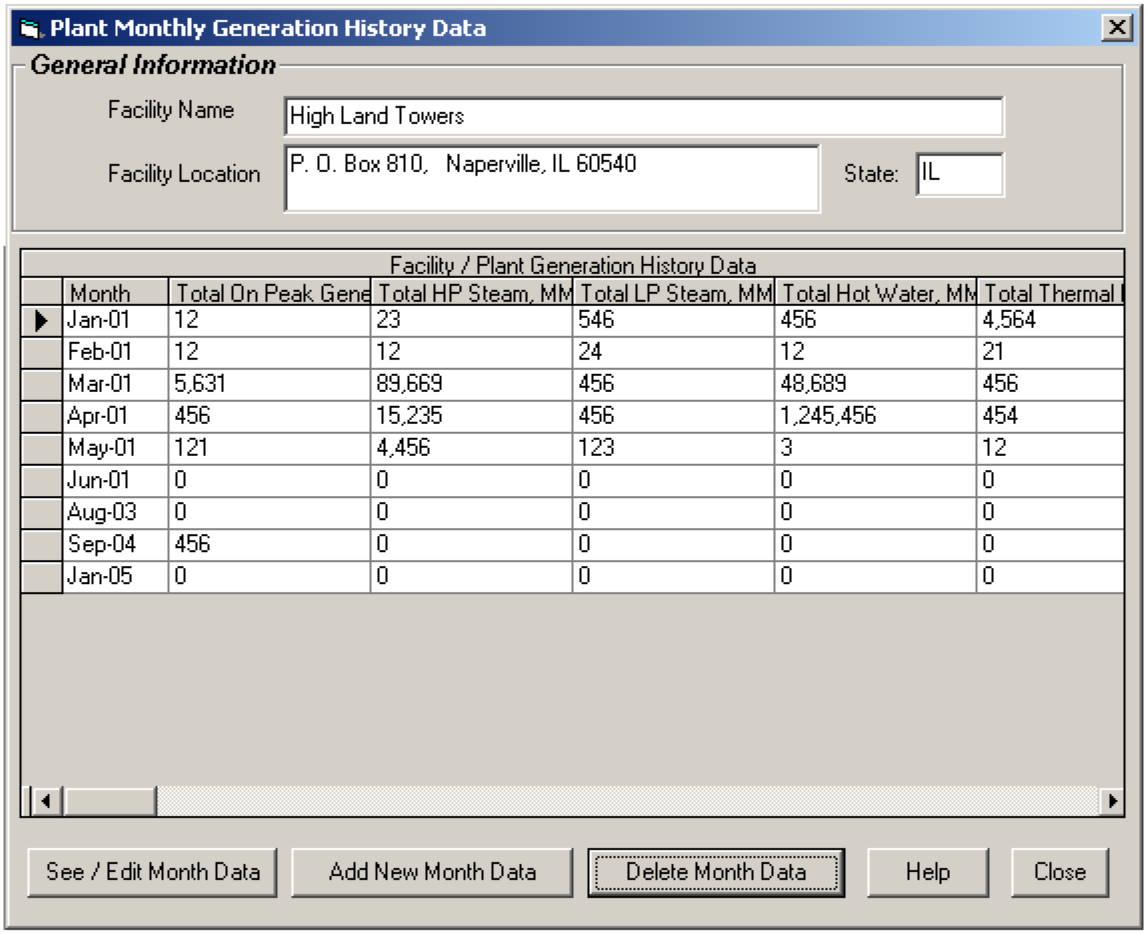
Use **Help** command to show the on-line help information for this form.

Close (OK) command

Use **Close (OK)** command to close the form, without (with) saving the update data.

Plant Monthly Generation History Data

Plant Monthly Generation History Data form is used to show all the monthly data for the plant. Also, it provides users options to review, edit, add and delete monthly data.


Plant Monthly Generation History Data

General Information

Facility Name: High Land Towers

Facility Location: P. O. Box 810, Naperville, IL 60540 State: IL

Facility / Plant Generation History Data

Month	Total On Peak Gene	Total HP Steam, MM	Total LP Steam, MM	Total Hot Water, MM	Total Thermal
Jan-01	12	23	546	456	4,564
Feb-01	12	12	24	12	21
Mar-01	5,631	89,669	456	48,689	456
Apr-01	456	15,235	456	1,245,456	454
May-01	121	4,456	123	3	12
Jun-01	0	0	0	0	0
Aug-03	0	0	0	0	0
Sep-04	456	0	0	0	0
Jan-05	0	0	0	0	0

See / Edit Month Data | Add New Month Data | Delete Month Data | Help | Close

<u>Plant Monthly Generation History Data Commands</u>

See / Edit Month Data command

Use the **See / Edit Month Data** command to be prompted to review or edit the related general information for the Plant on the form of Plant Month Data. One specific month should be highlighted from the month list before clicking on the command.

Add New Month Data command

Use the **Add New Month Data** command if you need to add a new Month Data for the plant. When you choose the Add New Month Data command, you will be prompted to specify a new Month / Year and the related information on the form of **Error! Bookmark not defined.**

.

Deleted Month Data command

Use **Delete Month Data** command if you need to delete the month Data for the plant from the DGRST database**.** One specific month should be highlighted from the month list before clicking on the command. **Warning**: once completion of the command, all the month data will be deleted and cannot be undone.

Help command

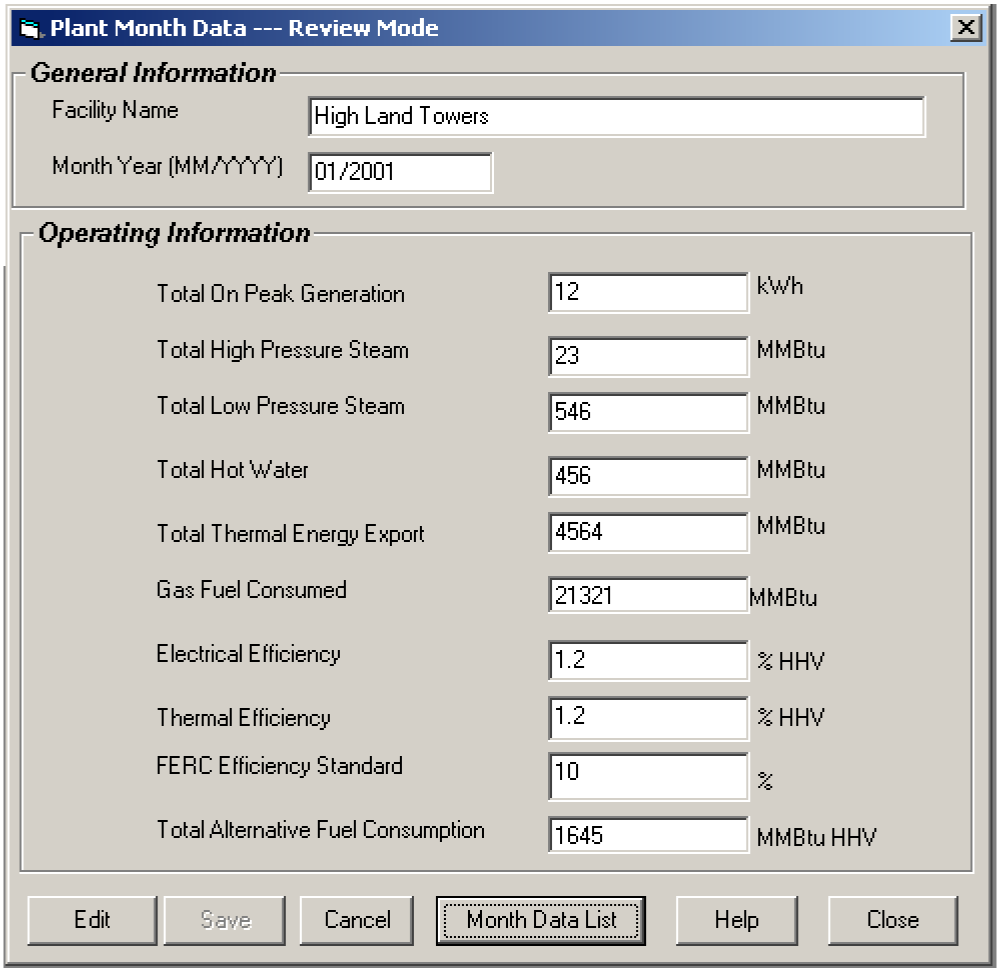
Use **Help** command to show the on-line help information for this form.

Close command

Use **Close** command to close the form.

Plant Month Data

Plant monthly history data can be edited, reviewed on this form.



<u>Plant Month Data Commands</u>

Edit command

Use **Edit** command to change the form into the editable mode. The data in the box with light green color can be edited directly. After Edit command executing, Save command will be enabled for saving the update data, and Close command will change to OK command for saving the update data and closing the form.

Save command

Use **Save** command to save all the data on the form. After Save command executing, the form change back to un-editable mode. The back color in data boxes will be light yellow, which means non-editable and only for display. The form changes back as the initial status, non-editable.

Cancel command

Use **Cancel** command to close the form, without saving any update data.

Month Data List command

Use the **Month Data List** command to be prompted to review the data of all the plant monthly generation history data on the form of **Error! Bookmark not defined.**

Help command

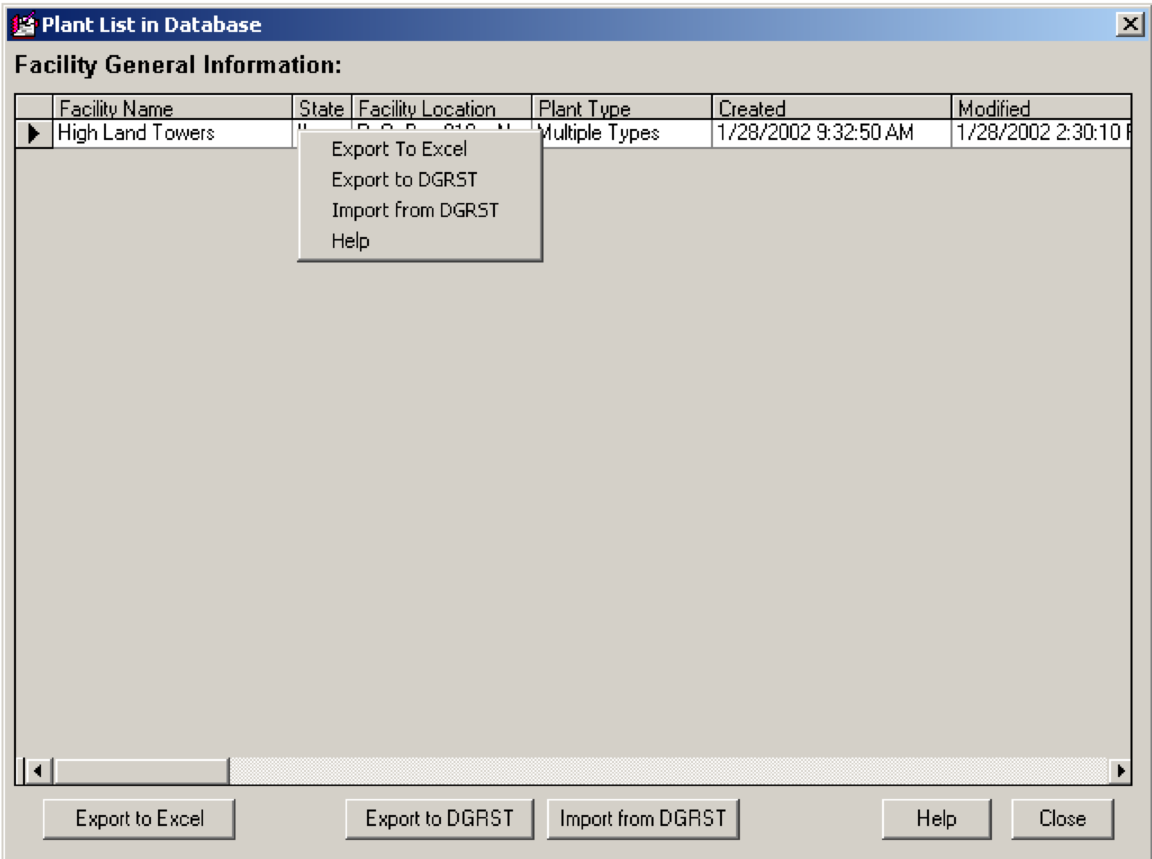
Use **Help** command to show the on-line help information for this form.

Close (OK) command

Use **Close (OK)** command to close the form, without (with) saving the update data.

Plant List in Database

Plant List interface allows user to manipulate sub-sections of the DGRST database by sending/exchanging it in a compact format that can easily be e-mailed.



Plant List in Database Commands

Export to Excel command

Use the **Export to Excel** command if you need to export the data of specific plant(s) to excel spreadsheet. All the information including Plant, Unit Event, Plant History Date, and Unit History Data cam be exported to either a new excel file or an existing excel file.

Export to DGRST command

Use the **Export to DGRST** command to allow users export the information collected using DG Reliability Survey Tool (DGRST) in a very compact format. In this way a full set of collected information associated with a specific plant can be conveniently sent/e-mailed to main location and appended to the main DGRST database (if preferred, a full DGRST database can be send as well).

Import from DGRST command

Use the **Import from DGRST** command to allow users import the information with DGRST format. All the information including Plant, Unit Event, Plant History Date, and Unit History Data in format of DGRST will be imported to the DGRST database directly.

Help command

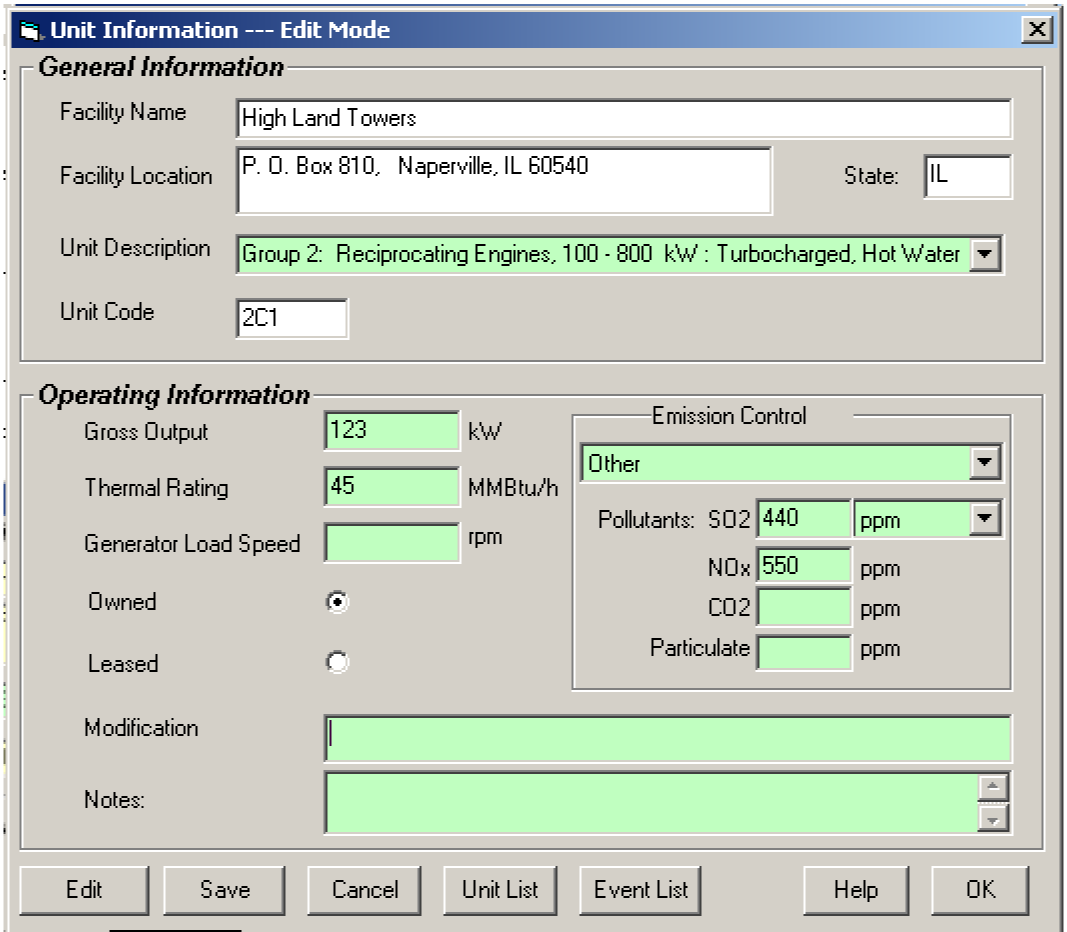
Use the **Help** command to show the on-line help information for this form.

Close command

Use the **Close** command to close the form.

Unit Information

Unit Information can be edited on this form



<u>Unit Information Commands</u>

Edit command

Use **Edit** command to change the form into the editable mode. The data in the box with light green color can be edited directly. After Edit command executing, Save command will be enabled for saving the update data, and Close command will change to OK command for saving the update data and closing the form.

Save command

Use **Save** command to save all the data on the form. After Save command executing, the form change back to un-editable mode. The back color in data boxes will be light yellow, which means non-editable and only for display. The form changes back as the initial status, non-editable.

Cancel command

Use **Cancel** command to close the form, without saving any update data.

Unit List command

Use the **Unit List** command to be prompted to review the list of all units for the plant on the form of **Error! Bookmark not defined.**

Event List command

Use the **Event List** command to be prompted to review all the events for the unit on the form of **Error! Bookmark not defined.**

Help command

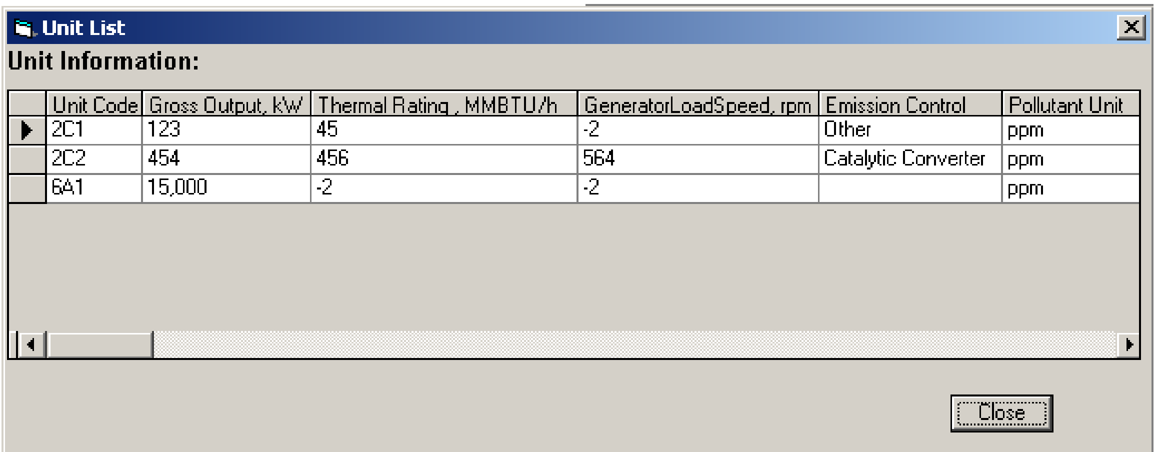
Use **Help** command to show the on-line help information for this form.

Close (OK) command

Use **Close (OK)** command to close the form, without (with) saving the update data.

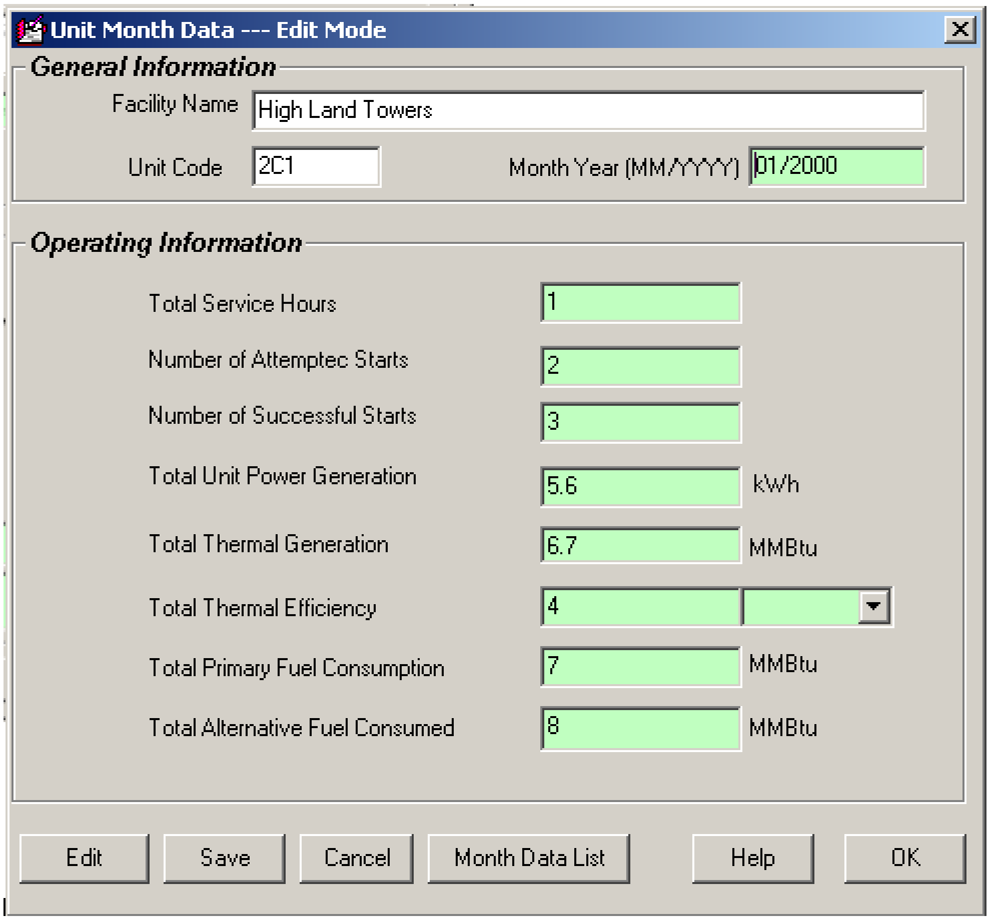
Unit List

Unit List Interface is used to show the data of all units in the plant.



Unit Month Data

Unit monthly history data can be edited, reviewed on this form.



<u>**Unit Month Data Commands**</u>

Edit command

Use **Edit** command to change the form into the editable mode. The data in the box with light green color can be edited directly. After Edit command executing, Save command will be enabled for saving the update data, and Close command will change to OK command for saving the update data and closing the form.

Save command

Use **Save** command to save all the data on the form. After Save command executing, the form change back to un-editable mode. The back color in data boxes will be light yellow, which means non-editable and only for display. The form changes back as the initial status, non-editable.

Cancel command

Use **Cancel** command to close the form, without saving any update data.

Month Data List command

Use the **Month Data List** command to be prompted to review the list of all the unit month data on the form of **Error! Bookmark not defined.**

Help command

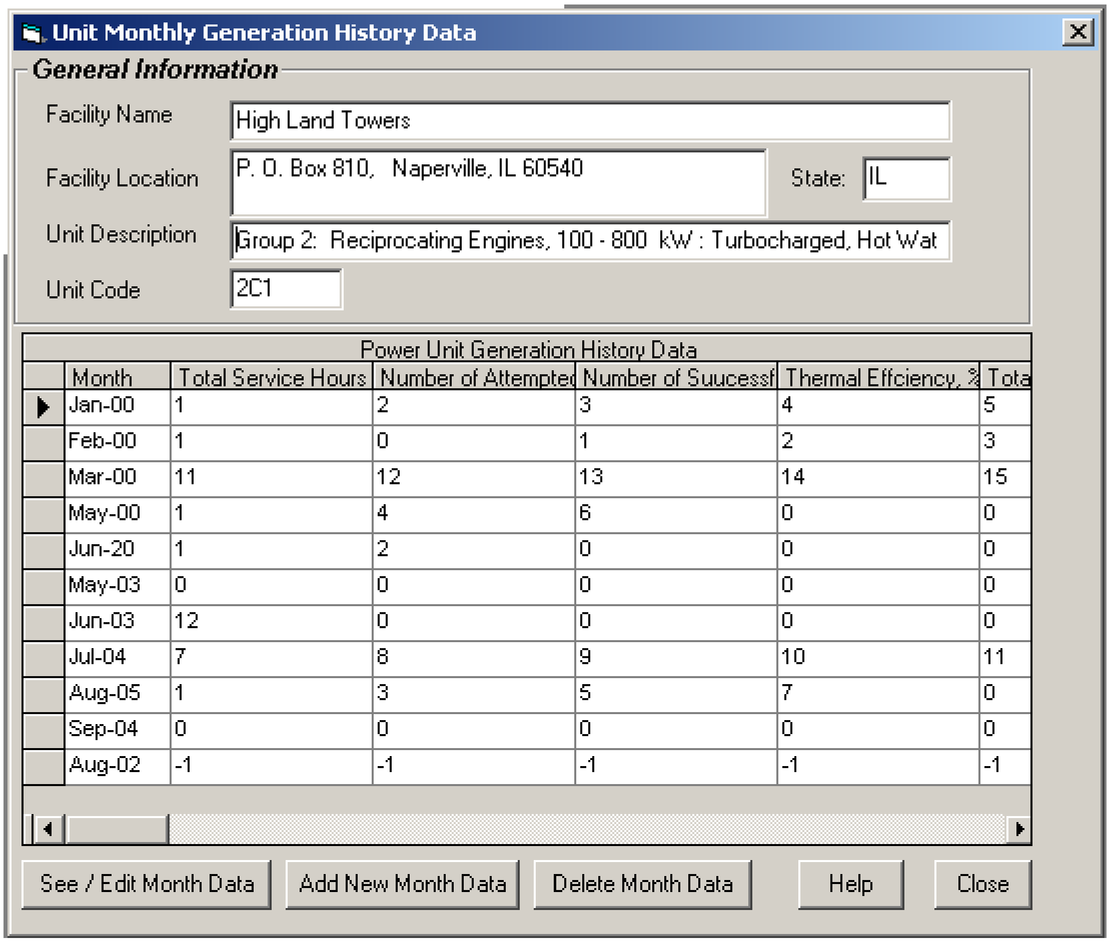
Use **Help** command to show the on-line help information for this form.

Close (OK) command

Use **Close (OK)** command to close the form, without (with) saving the update data.

Unit Monthly Generation History Data

Unit Monthly Generation History Data form is used to show all the monthly data for the Unit. Also, it provides users options to review, edit, add and delete monthly data.


Unit Monthly Generation History Data

General Information

Facility Name: High Land Towers

Facility Location: P. O. Box 810, Naperville, IL 60540

State: IL

Unit Description: Group 2: Reciprocating Engines, 100 - 800 kW : Turbocharged, Hot Wat

Unit Code: 2C1

Power Unit Generation History Data

Month	Total Service Hours	Number of Attempted	Number of Suucessf	Thermal Effciency, %	Tota
Jan-00	1	2	3	4	5
Feb-00	1	0	1	2	3
Mar-00	11	12	13	14	15
May-00	1	4	6	0	0
Jun-20	1	2	0	0	0
May-03	0	0	0	0	0
Jun-03	12	0	0	0	0
Jul-04	7	8	9	10	11
Aug-05	1	3	5	7	0
Sep-04	0	0	0	0	0
Aug-02	-1	-1	-1	-1	-1

See / Edit Month Data | Add New Month Data | Delete Month Data | Help | Close

<u>**Unit Monthly Generation History Data Commands**</u>

See / Edit Month Data command

Use the **See / Edit Month Data** command to be prompted to review or edit the related month data for the unit on the form of **Error! Bookmark not defined.** One specific month should be highlighted from the month list before clicking on the command.

Add New Month Data command

Use the **Add New Month Data** command if you need to add a new Month Data for the unit. When you choose the Add New Month Data command, you will be prompted to specify a new Month / Year and the related data on the form of **Error! Bookmark not defined.**

.

Deleted Month Data command

Use **Delete Month Data** command if you need to delete the month Data for the unit from the DGRST database**.** One specific month should be highlighted from the month list before clicking on the command. **Warning**: once completion of the command, all the month data will be deleted and can not be undone.

Help command

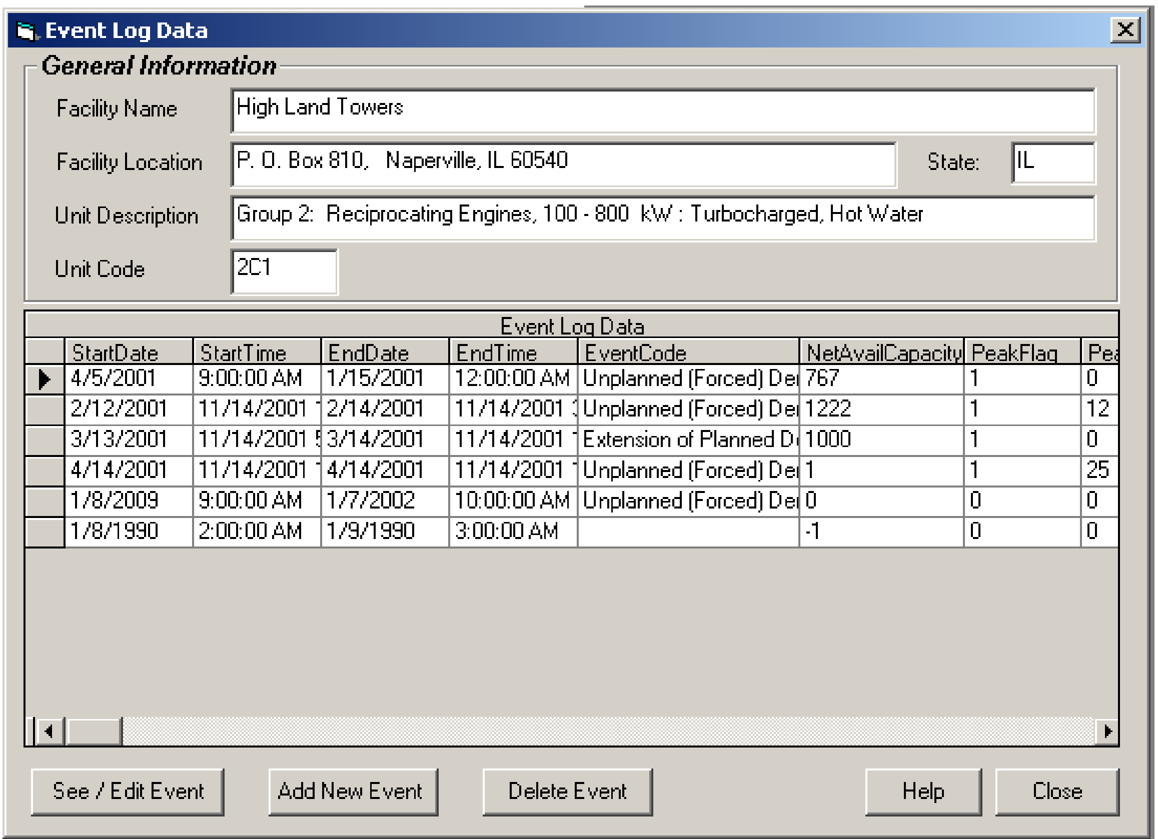
Use **Help** command to show the on-line help information for this form.

Close command

Use **Close** command to close the form.

Event Log Data

Event Log Data form is used to show all the events for one unit. Also it provides users option to review, edit, add and delete the event for the unit.



Event Log Data Commands

See / Edit Event command

Use the **See / Edit Event** command to be prompted to review or edit the related information for the event on the form of **Error! Bookmark not defined.**. One specific event should be highlighted from the event list before clicking on the command.

Add New Event command

Use the **Add New Event** command if you need to add a new event for the plant. When you choose the Add New Event command, you will be prompted to specify a new event and its related information on the form of **Error! Bookmark not defined.**

.

Deleted Event command

Use **Delete Event** command if you need to delete the event Data for the unit from the DGRST database**.** One specific event should be highlighted from the month list before clicking on the command. **Warning**: once completion of the command, the event data will be deleted and can not be undone.

Help command

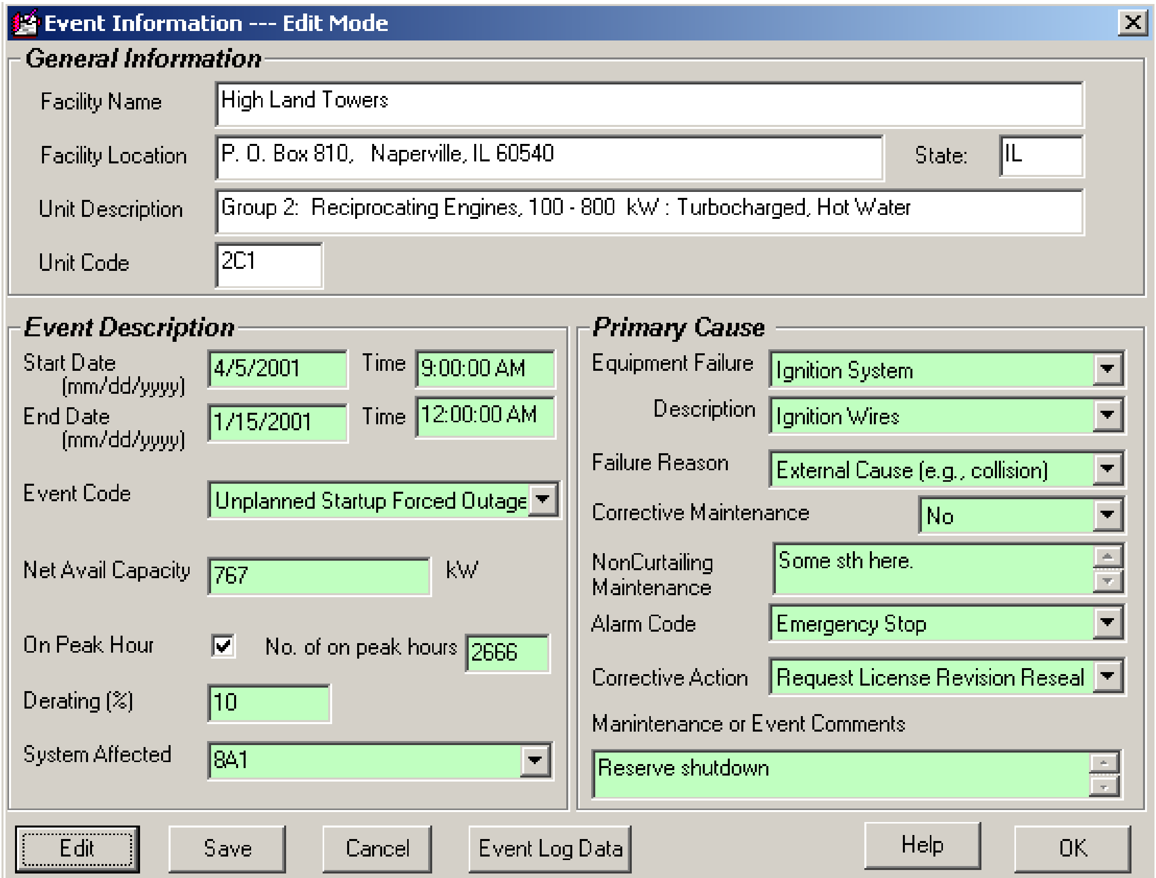
Use **Help** command to show the on-line help information for this form.

Close command

Use **Close** command to close the form

Event Information

Specific event data for one unit can be reviewed / edited on this form.



<u>**Event Information Commands**</u>

Edit command

Use **Edit** command to change the form into the editable mode. The data in the box with light green color can be edited directly. After Edit command executing, Save command will be enabled for saving the update data, and Close command will change to OK command for saving the update data and closing the form.

Save command

Use **Save** command to save all the data on the form. After Save command executing, the form change back to un-editable mode. The back color in data boxes will be light yellow, which means non-editable and only for display. The form changes back as the initial status, non-editable.

Cancel command

Use **Cancel** command to close the form, without saving any update data.

Event Log Data command

Use the **Event Log Data** command to be prompted to review the list of all events for the unit on the form of **Error! Bookmark not defined.**

Help command

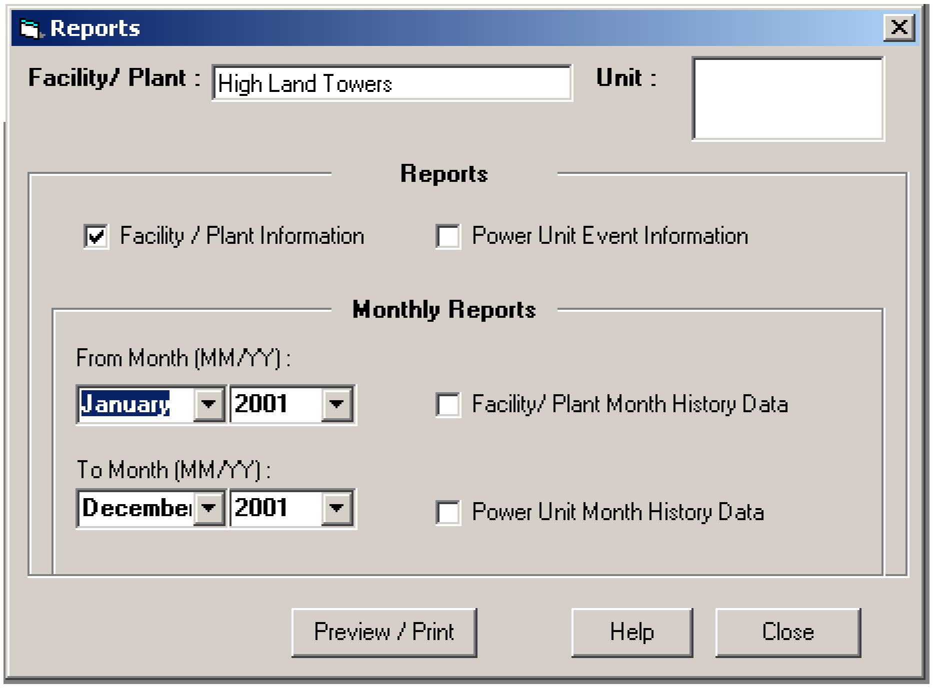
Use **Help** command to show the on-line help information for this form.

Close (OK) command

Use **Close (OK)** command to close the form, without (with) saving the update data.

Reports

The reports for plant data, unit data, event data, and monthly generation data can be previewed and printed after the specific report(s) selected.



__Reports Commands__

Help command

Use **Help** command to show the on-line help information for this form.

Close command

Use **Close** command to turn off the form.

Preview / Print command

Use **Preview / Print** command to preview or print the selected report(s).

APPENDIX C DG/CHP RELIABILITY DATABASE

APPENDIX D
TECHNOLOGY/DUTY CYCLE SUMMARY REPORTS AND UNIT CHARACTERIZATION REPORTS